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A TEXT-BOOK

ON

# GAS, OIL, AND AIR ENGINE

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# A TEXT-BOOK

ON

# GAS, OIL, AND AIR ENGINES;

OR,

## INTERNAL COMBUSTION MOTORS WITHOUT BOILER.

BY

BRYAN DONKIN, JUNR.
MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS.

WITH 136 ILLUSTRATIONS.

LONDON:
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# PREFACE.

THE subject of Internal Combustion Motors, or engines for obtaining power without a boiler, is one of great and increasing importance, and it was, therefore, with pleasure that I undertook the following work at the request of the publishers.

It is divided into three parts, treating respectively of Gas, Air, and Oil Engines. Part I., Gas Engines, is divided into two sections, the first dealing with the early history of these motors, and the second with modern gas engines. In this latter part particularly I am much indebted to numerous recognised authorities on the subject, especially to the excellent works of Professors Schöttler and Witz, Mr. Dugald Clerk, Professors Jenkin and Robinson, M. Chauveau, and others. Information has also been obtained from the *Proceedings of the Institution of Civil Engineers*, *Proceedings of the Institution of Mechanical Engineers*, *Comptes Rendus de la Société des Ingénieurs Civils*, *Zeitschrift des Vereines deutscher Ingenieure*, *The Engineer*, *Engineering*, and various other scientific and technical periodicals. A list is given of the literature of the subject, both English and foreign, which, it is hoped, will be found fairly complete.

The Theory of the Gas Engine is briefly discussed in

four chapters, and here I have had the advantage of the remarks and valuable criticism of Professor Capper, of King's College, London, who also kindly made for publication in this work a new test upon the experimental Otto-Crossley gas engine in the engineering laboratory of King's College—a test which is, perhaps, as complete as any that have been published. Chapter XVII., on the "Chemical Composition of Gas"—an important part of the subject—has been entrusted to Mr. G. H. Huntly, A.R.C.S. of the State Medicine Laboratory, King's College, who is responsible for this chapter only.

Care has been taken to consult the best authorities in England and on the Continent who have written on the theory and practice of gas engines, and to bring the matter up to date. I have much pleasure in acknowledging my special obligations under this head to M. Delamare-Deboutteville of Rouen, and Professor Schröter of Munich, for their kind assistance. To Professor Kennedy, F.R.S., also, who has made many exhaustive and reliable tests on English gas engines, my acknowledgments are due. Not much original work appears to have been done in the United States, but the subject has been thoroughly studied in France and Germany.

An Appendix is added, in five Sections, containing information which it was not found possible to incorporate in the text. One of them gives an abstract of the valuable experiments recently made by Dr. Slaby of Berlin, and published after the main portion of this work was complete.

In conclusion, there only remains for me to emphasize the fact of the constantly increasing use of these motors in all countries for industrial purposes. Undoubtedly,

there is a great future before them. There still exists, however, a large field for economy. In both Oil and Gas Engines, about 40 per cent. of all the heat received now goes off in the exhaust gases, and about 35 per cent. in the jacket water. The better the economic results obtained, the greater will be the demand for these convenient motors. At present their chief recommendation is the absence of a boiler, which is of great advantage, especially for small powers. Even with the very high temperatures in the cylinders there is also little or no difficulty with lubrication. They are yearly increasing in size and power,* and will certainly before long, as more knowledge and experience are brought to bear on their construction, enter into formidable competition with the best steam engines. They may even constitute the principal heat motors of the future.

A list has been added of the chief tests on Gas, Oil, and Air Engines that have been published up to date.

BRYAN DONKIN, J^R.

LONDON, *November, 1893.*

* On going to press a notice of a Three-Cylinder Horizontal Double-acting Compound Gas Engine, indicating 600 to 700 H.P., is given in *The Engineer* of November 10, 1893.

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# A TEXT-BOOK OF

# GAS, OIL, AND AIR ENGINES.

## PART I.—GAS ENGINES.

### CHAPTER I.

### GENERAL DESCRIPTION OF THE ACTION AND PARTS OF A GAS ENGINE.



THE principles governing the construction and action of a gas motor are almost the same as those of a steam engine. In both the object is to obtain useful work from heat. This is effected by raising gas or water to a certain temperature, producing in the one case steam, in the other flame, and with the pressures resulting from the increase of heat in the steam or flame driving forward a piston connected to a shaft. The science of thermodynamics proves that there exists a strict ratio between the heat evolved and the work performed. The laws governing the production of this heat energy are always the same, whatever the medium or agent of motive force.

In all mechanical motors there are three factors to be considered:—1st. The cause of motion, varying according to the type of motor. In heat engines it is caloric obtained in various ways, as from combustion of coal in a boiler or hot air furnace, or by the explosion of inflammable gases. 2nd. The effect produced, or the energy into which the heat is transformed; this usually takes the form of pressure upon a piston working on to a crank. So far, all heat motors are alike. 3rd. The particular mechanism, differing in each kind of motor, by which this translation of heat into work is utilised. The difference between steam and other kinds of motors, such as gas, hot air, petroleum,

&c., lies in the means employed to generate the heat, and turn it into work.

A steam motor consists of three indispensable parts, the furnace, the boiler, and the cylinder containing the motor piston. These may be in close proximity to each other, but there is usually a separate building for the boiler, &c. The process of starting a steam engine is relatively slow and laborious. The fire must be kindled and combustion obtained in the furnace, and the water in the boiler brought to boiling point and evaporated into steam. The temperature must then be raised until the pressure of the steam, produced by the increase of temperature, is sufficient to propel the motor piston.

**Advantages of a Gas Engine.**—In a gas engine these operations are much simpler, because it is so constructed that, for the work it has to perform, it is complete in itself, containing on one foundation the equivalent of furnace, boiler, and cylinder. It is in the cylinder that the production and utilisation of the heat takes place, and the entire cycle, or series of operations, is completely carried out. Highly inflammable gases and air are first admitted into the cylinder. They are, at a given moment, exploded by the application of heat or flame; the pressure and the temperature are at once considerably raised, and the piston is driven forward. In a steam engine the working agent is produced separately and continuously, but in a gas motor the inflamed gases, which act as the medium of heat, must be generated afresh at each stroke of the piston. With gas there is very little difficulty in obtaining an explosion, and a corresponding backward and forward stroke, as many times in a minute as is required. As combustion takes place in the cylinder itself, pressures and temperatures much greater than those developed in steam engines are easily and quickly produced. Hence gas motors are called "internal combustion" engines, and the same name is used for all motors in which the heat is generated inside, instead of outside, the cylinder.

This brief outline of the working of a gas motor shows the advantages it possesses in practice over the steam engine—namely, compactness and facility in starting. Theoretically, it is also superior, because higher temperatures and higher pressures are available, to act upon the piston. But in all heat motors hitherto made, there are defects which the skill of the best constructors has not yet been able to overcome—namely, waste of the greater part of the heat generated, and consequent loss of pressure, or of useful work done upon the piston.

Considering, first, the practical advantages of the gas engine, as far as compactness is concerned, it leaves little to be desired. The space it occupies is small, a few square feet being sufficient, instead of the separate boiler and chimney nece[illegible] [illegible] steam engine. A gas motor can be fixed almost [illegible]

it should stand on a solid foundation, to counteract the vibrations caused by the repeated explosions. To place it in proper working condition, all that is required is a gas supply pipe, and a water tank with pipes for cooling the cylinder. The high temperatures produced by the explosion of the gases necessitate the use of a jacket round the cylinder, through which water circulating automatically from a tank passes continuously, to keep it cool; this jacket water is used over and over again. These pipes, with a third communicating with the outer air, and providing an outlet for the burnt gases, constitute all the necessary working connections.

A gas engine thus easily fixed, can also be set in motion and started in a few minutes. If a gas jet or hot ignition tube is used to fire the charge, it is of course previously lighted; where combustion is obtained electrically, the generation of the sparks is produced before the engine is started. A few turns by hand or other means are given to the flywheel, while the exhaust is kept open, and the engine is then fairly at work. To stop it, nothing is needed but to turn off the supply of gas. For small manufactures the convenience of having a motive power at hand, easy to start or stop in a few moments, is so great, that small gas motors are rapidly superseding, not only steam, but manual labour. It cannot be denied that they are rather more costly than steam, but of late years their consumption of gas per H.P. has been much reduced. In proportion as the quantity of gas required to drive them is diminished, and the economy obtained is greater, the more popular and cheaper will they become. Practically, there is less danger of fire than with steam boilers, and thousands of gas engines are now used in places where steam could never be employed.

It is in the smaller gas engines that these practical advantages are chiefly felt, but the theoretical superiority of these motors, obtained by the high temperatures at which they can be worked, apply equally to engines of all sizes. But as soon as large powers are required, and the gas engine enters into active competition with steam, it becomes of far greater importance to economise the consumption of gas. The temperatures and pressures obtained by the inflammation and explosion of gas in a cylinder are so high, that engineers have not yet succeeded in utilising them to their full extent. Hence, there is much waste of heat and consequent loss of pressure, and these defects in the working of a gas engine affect injuriously the expenditure of gas. If heat be wasted, more must be supplied, and more gas must be used to produce it.

**Waste of Heat.**—In a steam engine the main object should be to keep the cylinder walls as hot as possible, to prevent the condensation of the steam. The difficulty of generating steam, and maintaining its temperature and pressure, is in-

creased, because there is a change of physical state from a liquid to steam. With a gas engine the reverse process is necessary, and the cylinder walls must be cooled. The gas is dry, and the heat developed by the explosions taking place in the cylinder acts directly on the piston. A considerable amount of steam is condensed in the pipes of a steam engine, whereas in a gas motor there is no similar waste, because all the heat is generated in the cylinder itself. Nevertheless heat is lost, but in a different way. The temperature of the gas at the moment of explosion is relatively high. It is generally assumed to be about 2,730° F. (1,500° C.), but this is known not to be the highest temperature reached. Whatever the actual temperature, the heat is always too great to be retained; a large portion is sacrificed, to prevent injury and destruction to the parts, and heat is also carried off continuously by the cooling water round the cylinder. In the early double-acting engines, not more than 4 per cent. to 6 per cent. of the total heat received was employed in doing work, and more than half was wasted, that the walls might be kept cool. If to this be added the heat escaping from the cylinder in the exhaust gases, or the products of combustion, it is not difficult to understand how, formerly, from 94 per cent. to 96 per cent. of the heat was dissipated.

It is this waste of heat in a gas motor that causes the loss of pressure, or diminution in the work done on the piston. With all gases the pressure increases with the rise in temperature, and, therefore, the higher the temperature, the greater will be the pressure produced, or the expansion of the gases. If this pressure be expended in doing work, and acting on the piston, the whole may, if expansion be continued long enough, be utilised in useful work. But to obtain this result with the pressures generated in a gas engine, the cylinder and piston must be of great length, and the piston allowed to move out as long as there is any expansive force left in the gas to act upon it. As this is practically impossible, the other plan is to diminish the quantity of gas admitted into the cylinder. Before compression was employed, it was difficult to proportion the supply of gas to the expansion, and it is a delicate process even in a modern engine, in which the gases are compressed before explosion.

When the theory of the gas engine began to be really understood, the principal problem was, how to obtain sufficient expansion from the exploded gases. The test of efficiency in any heat engine is the proportion between the total heat supplied, and the total useful work obtained. As far as work is concerned, all the heat which is not employed in producing it is wasted. Thus to be really efficient, a gas engine ought to furnish a maximum amount of useful work with a minimum [illegible] of gas. This is only possible if the expansion [illegible]

rapid and prolonged. The greater the time allowed them to act upon the piston, and the farther they drive it, the more heat energy will be expended in work, and the less will be discharged as waste into the atmosphere. Expansion should also be rapid, because the more quickly the piston uncovers successive portions of the cylinder walls, the less time will there be for useful heat to be carried off from the hot gases to the cooler walls. This important question of expansion will be more fully examined, when considering the theory and utilisation of heat in a gas engine.

The study of a gas engine falls naturally into two divisions:—

I. The source of power, or motive force.
II. Its mechanical utilisation.

**I. Source of Power.**—In all heat engines the source of power is heat, and gas is the medium or agent through which it acts in a gas motor. The gas is ignited, and the explosive force thus generated is used to drive forward a piston. Many different kinds of gas, varying in heating value, are employed, and the effects obtained by ignition and explosion cannot be determined without a knowledge of the chemical constituents of the gas, and the proportions in which they combine with air. Since the gas used in an engine cylinder does not contain the oxygen necessary for combustion, it can never be burnt by itself, but must always be diluted with a certain quantity of air. Unless the composition of the gas and the ratio of its dilution with air are known, it is impossible to ascertain the temperatures and pressures attained in the cylinder, and to calculate the theoretical work, or the work it ought to do. The study of gases has led to the discovery of the law of dissociation, or the property they possess, after they have attained a certain high temperature, of resolving into their separate elements. The phenomena of ignition in a cylinder also prove that the whole heat of the gases is never developed at once, whatever the gas used, or the proportions in which it is diluted with air. It appears probable that combustion is seldom complete and instantaneous, but continues during the forward motion of the piston, after the first propagation of heat which causes the explosion. These and other questions connected with the phenomena of combustion in a gas engine are only mentioned here, and will be discussed later.

**II. Utilisation of the Explosive Force, &c.**—In the second part of the subject we have to consider the mechanical utilisation of the motive force, or the method by which it is turned into rotatory motion. This includes a study of the construction and parts of a gas engine, as the apparatus used for the transformation of heat into useful power. There is this peculiarity in its structure, that the cylinder contains in itself

furnace and boiler, and in it the motive power is developed. Before examining in detail the various types, it will be well to explain the principal parts of a gas motor, and its internal organisation. We will first enumerate these parts, and then describe the functions they have to perform, as also the different operations taking place in a gas engine.

**Base.**—The base plate on which the engine is fixed is of cast iron, and usually very solid. In some engines it forms a hollow casing on which the cylinder is bolted, and the air for diluting the gas is often drawn through it. In many of the modern horizontal motors using compression, the hollow base acts as a reservoir, and the mixture of gas and air is compressed into it, before passing through to the motor cylinder.

**Cylinder.**—The cylinder, solidly bolted to the base, is either vertical or horizontal, according to the type of motor. Few gas engines have more than one motor cylinder, working single acting; it is almost always open to the atmosphere at the crank end, and closed only by the piston. Except for large sizes a second cylinder is seldom needed to increase the motive power, sufficient force being obtained by the succession of explosions in one cylinder. With higher powers two or more single-acting cylinders are usually employed. As the great object in a gas engine is to allow the gases to expand as completely as possible, it seems at first as though this end would be best attained by making the engines compound, like steam engines, and causing the gases to expand successively in different cylinders. Though often tried, this arrangement has rarely been found successful. Sometimes an auxiliary pump is used for compressing the mixture, or a charging cylinder for receiving and mixing the gas and air. Occasionally compression is obtained in the motor cylinder itself, and the motor piston acts on one side as a pump. A special feature of gas engine cylinders is that, on account of the great heat developed, they are always provided with some apparatus for cooling the walls. In the smallest types it has been found sufficient to make the outer radiating surfaces of the cylinder ribbed or deeply indented, exposing a large cooling area to the air. In engines developing above two or three horse-power, a jacket with water constantly circulating through it is indispensable. As one end of the cylinder is almost always open to the air, the cylinder metal is kept cool, and overheating is prevented by contact with the outer air, but chiefly by the water jacket.

**Pistons.**—The pistons of gas motors are very similar to those of steam engines, but longer. One or two types have valves in the pistons, to admit air or discharge the exhaust gases. Plunger pistons are generally used.

**Valves.**—The valves of a gas engine have mo functions to perform than the admission and exh

a steam engine. Not only do they admit the gases into the cylinder and discharge the products of combustion, but they are frequently used to assist in mixing and firing the gas and air. In the older types of engine, as in the early Otto, there is generally one slide valve for admitting, mixing, and igniting the charge. It contains ports to receive and pass on the gas and air to the cylinder, and carries a lighted flame within a cavity to kindle the charge, after it is mixed and compressed. In most modern engines lift valves alone are used, but occasionally the mixture is admitted to the cylinder through cylindrical or piston valves, or a revolving disc. In most engines the valves are worked by cams on a side shaft driven from the main shaft, or by eccentrics; in others they are automatically lifted or closed by the pressures in the cylinder.

**Transmission.**—As in a steam engine, the power is generally transmitted direct from the piston-rod and connecting-rod to the crank shaft, but sometimes through intermediate parts. Occasionally there is no connecting-rod, the piston working direct on to the shaft. To obtain greater regularity in the action of the engine, the flywheel is usually made larger and heavier than in steam engines. Most gas engines have only one explosion per two revolutions, and the energy of the flywheel is required to carry the piston forward, take in a fresh charge of gas and air, and to bring it back to the dead point after explosion.

In all gas engines five operations are required for a complete cycle—I. Admission and mixture of the charge of gas and air. II. Ignition. III. Explosion. IV. Expansion. V. Exhaust, or the discharge of the gases and products of combustion. To these has been added in most modern engines a sixth, namely, VI. Compression. This cycle of work corresponds to each explosion, but not necessarily to each revolution; indeed, in many engines the number of revolutions and of explosions are independent of each other. The nature of these operations is as follows:—

**I. Admission of the Gas and Air to the Cylinder.**—This was formerly supposed to be a complicated process, and great care was taken to provide separate valves for admitting the air, and conducting the charge to the cylinder. Experience has shown that the air enters freely through any aperture, which is usually placed in proximity to the gas admission valve. Gas, unless made specially on the spot, is admitted through a pipe from any ordinary gas main. In the older engines, admission of the charge is made through a slide valve, as already described, moving to and fro between the slide cover and the cylinder. The gas pipe communicates with a passage in the slide cover, and a hole in the slide valve leading to a cavity. As soon as the cavity is filled with gas, the movement of the slide brings it opposite a similar opening in the cylinder, through which the gas

enters. In later engines admission is effected through ordinary lift valves. Before entering the cylinder, the gas usually passes through a chamber where it is thoroughly mixed with its proper proportion of air, admitted through a separate inlet. Much importance was attached to this process of mixing before the use of compression, and different methods were resorted to, either to mix the gas and air, or to keep them in separate layers, and stratify them as they entered the cylinder. It is now almost universally admitted that these arrangements do not influence the explosion, and that stratification does not take place in the manner supposed, owing to the compressive force exerted by the piston. The gas admission valve is usually connected to the governor, which regulates the quantity of gas entering, and consequently the number or strength of the explosions.

**II. Ignition.**—The gases being admitted into the cylinder, the next operation is to fire or ignite them. This is usually a delicate process, because the return stroke of the piston exerts a considerable pressure upon the incoming charge, which may blow out the flame. The difficulty is increased in modern engines by the previous compression of the gas and air. Three methods of ignition are employed. 1. The electric spark. 2. A gas jet constantly burning. 3. A tube maintained at a red heat by a gas burner. Electricity was the first means proposed and adopted for igniting the gases, and it is still largely used in French engines. A current of electricity passes along wires placed close to the valve or chamber admitting the charge of gas and air, sparks are continually formed and fire the mixture. As the electric spark is sometimes found to be precarious in action, missing fire, and the charge is not ignited, an electric hammer is used to obtain a continuous stream of sparks. With flame ignition the charge, after being admitted into the slide valve and mixed, is, in compression engines, carried past a flame burning in a hollow of the valve. When the mixture is ignited the pressure of the burning gas often puts out the flame, and it is then relighted by an external permanent burner. The slide valve is held against the back of the cylinder, and is worked by an eccentric, but more often by a cam on the auxiliary or counter shaft driven from the main shaft. In England the most general method of ignition is, at present, by a hot tube. At a given moment the opening to this tube is uncovered, a portion of the charge at high pressure is brought in contact with it and fired, and explodes the remainder in the cylinder. The tube is kept at a red heat by a gas burner, and is easily replaced from time to time when it is worn out. Formerly these tubes were made of iron, and were "short-lived" as it is termed; but now very small tubes of platinum and other metals are used, which last much [illegible]. In some of the older types of engines, where the [illegible] admitted at atmospheric pressure, the gas [illegible]

at one end of the cylinder by the suction of the forward stroke of the piston. At a certain moment a small flap valve covering a flame burning on the outside of the cylinder is lifted by the pressure, the flame drawn forward, and the mixture thus ignited. Sometimes the piston itself, in its out stroke, is used to uncover the gas and air valves. In other engines the gases are ignited in a separate chamber; there is no explosion, but they enter the cylinder in a state of flame, and force the piston forward.

**III. and IV. Explosion and Expansion.**—It is in the motor cylinder that explosion and expansion of the ignited gases almost always take place. To allow room for the compression and ignition of the charge, the clearance space is usually much larger than in steam engines, sometimes so large that it forms a separate chamber, into which the gas mixture is compressed. In the earlier types of gas motors, the charge was drawn in during the first part of the forward stroke, explosion taking place only when the piston had almost reached the middle of the cylinder. It was soon found that this tardy explosion greatly limited the number of expansions, and the work performed by the gases on the piston. Later engines were designed to procure the explosion as near the beginning of the stroke as possible, so as to allow the maximum volume of the cylinder for the expansion of the gases. In some vertical non-compression engines the clearance space is exceedingly small. Explosion of the gases takes place when the piston is at the bottom of its stroke, free of the crank and shaft, and drives it to the top of the cylinder.

**V. Exhaust,** or discharge of the gases.—Various methods are employed in gas engines for clearing the cylinder of the products of combustion. The unburnt gases are not at present utilised, like the exhaust steam in a condensing steam engine, and there is much conflict of opinion as to whether they should be completely expelled from the cylinder, or partly retained to mingle with the fresh charge. Most modern gas motors being single acting, or acting on one side of the piston only, the exhaust valve is seldom opened during the forward stroke. In some engines it only opens during half the return stroke, in others the whole of this stroke is utilised to expel the previous charge, while in a few engines a complete stroke, forward and return, is sacrificed to discharge the products of combustion, and cleanse the cylinder. Air under pressure is admitted to help the discharge in some modern engines. The exhaust valve plays an important part in a gas engine, because the high pressure in the cylinder is, of course, instantly reduced as soon as it is opened. Most gas engines are so constructed that the unburnt gases are allowed to escape at a relatively high pressure and temperature, which are thus wasted instead of being utilised. This is one of the defects of these motors which engineers should

be most anxious to remedy. In some vertical engines the piston is forced up by the explosion and driven down by atmospheric pressure, a vacuum being formed below by the cooling of the gases. The opening of the exhaust valve at the bottom of the cylinder, by causing the air to enter, equalises the pressure above and below the piston, and checks its descent. In the earlier engines the exhaust was usually connected to the admission and ignition valves, and one slide valve was made, during its motion to and fro, to uncover the three different openings. In others, and generally in the modern horizontal engines, the exhaust is under the cylinder, distinct from the admission valves, but worked from the same side shaft.

**VI. Compression** of the charge.—The sixth operation in a gas engine is the compression of the gas and air before ignition. This is the most important modern improvement introduced into these motors. As compared with the other operations, compression has certainly great influence on the consumption of gas, and on the economical working of the engine. It is effected in the following way :—A certain quantity of gas and air, in definite proportions, are admitted into the cylinder. Instead of being immediately ignited the mixture is compressed, and its pressure raised—that is, the volume of gas and air is forced into a much smaller space than before, either by the return stroke of the motor piston, or by that of a separate pump. If, for example, the charge occupied a space of 5 cubic feet, it is driven back by the piston till it occupies only, say 1 cubic foot, or one-fifth the previous space, and the pressure is raised five fold. The method usually adopted is to allow the piston to move out, and take in gas and air behind it till the whole cylinder is filled; the piston then returns, all the valves and ports being closed, and the mixture is driven into the clearance space and compressed. The advantages of this process are, that the particles of gas and air are forced much more closely together, and when they are ignited, their power of expansion has been found by experiment to be much greater. Nor do they part with their heat so quickly, being confined in a smaller space. Writers on the gas engine are unanimously of opinion that compression, previous to ignition, is the one great source of economy in gas motors, and this is confirmed by experiments. In the older non-compressing gas engines, it was always difficult to raise the pressure of the gases high enough to obtain much work on the piston. In modern compression engines, on the contrary, the expansive force of the gases is greater than can be properly utilised.

The advantages of compression are—(1) *T*
*cylinder required.* In the early engines, to
working pressure, the cylinders were made
gas and air as possible admitted at a tin

pressure was often very low. But with engines using compression, since the same charge occupies a smaller space, the cylinder can be made smaller. (2) *Greater certainty and rapidity of explosion*. It is true that to ignite the charge, when compressed, is more difficult than when it is at atmospheric pressure, but the particles of gas, being closer together, ignition proceeds more rapidly when once started, and a more vigorous explosion is obtained. The flame is easily and surely transmitted, permeates the whole mass almost instantaneously, and the entire force of the explosion is developed. (3) *Greater economy of gas*, because, inflammation being certain, a poorer quality of gas can be used. Not only may the quantity be smaller in proportion to air, but the weaker charge, if compressed, will still explode, even when further diluted with the products of former combustion. (4) As a *smaller cylinder is required for the same power*, there is less wall surface to carry off the heat generated by explosion. (See Chapters xviii. and xix., where this subject is fully treated.)

Compression is carried out in two ways. If the engine has only one cylinder, it takes place in the motor cylinder itself, and a complete stroke, to and fro, is generally sacrificed to obtain it. If a pump is added, the charge is compressed in it; every stroke of the motor piston is then a working stroke, and the flywheel obtains an impulse at every revolution. The pump is worked from the crank shaft, and the six operations are divided between the two cylinders. The pump piston admits and compresses the charge, which is then exploded and expanded, and the products of combustion driven out from the motor cylinder. The two pistons work more or less simultaneously, and the forward stroke of the pump draws in the fresh mixture, during expansion of the charge in the motor cylinder. In other engines the pump is worked from a separate crank, set slightly in advance of the main crank. This cycle of operations is good, but its advantages are counterbalanced by the additional power required to drive the pump. Occasionally the gas and air are compressed into a separate receiver, and in a few engines the front part of the motor piston takes the place of the pump, and compresses the charge.

**Oiling, &c.**—Lubrication, starting, and regulation of the speed in a gas engine, each require a few words of explanation. Oiling the piston is a matter of much importance, and must be carefully performed. The high speeds and temperatures at which gas motors work necessitate a continuous and skilful use of good mineral oil. In steam engines there is generally a certain amount of water, but the flames of a gas engine dry the internal urfaces, and unless oil is continuously applied, the cylinder soon es hot and begins to suffer. Hence the importance of ubrication in all gas engines. They are usually fitted

with a special apparatus for oiling the various parts automatically.

Small gas engines can be quickly started, but with large powers the process is not always easy. The engine should be at work in a few minutes, and the inertia of the working parts has to be overcome. All the larger motors are provided with special means of starting, such as a receiver, into which a reserve charge of gas and air is compressed, or a handle or cam acting upon the exhaust valve to keep it open, thus reducing the pressure in the cylinder. Sometimes a small auxiliary gas engine is used. MM. Delamare-Deboutteville and Malandin claim to have introduced an entirely new system, first shown in their Simplex engine at the Paris Exhibition of 1889. Other devices for starting have lately been patented.

**Regulation of Speed.**—To regulate the speed of an engine is rather a complicated process, and is effected in a variety of ways. Many different kinds of governors are used, though the majority are constructed on the principle of a weight acting by centrifugal force. A common type is the ball governor, but pendulum and air governors are also employed, while some governors are regulated by weighted arms or levers. The governor is generally in connection with the gas admission valve, but sometimes with the exhaust valve. The following are the usual methods of governing:—

1. By regulating the opening, more or less, of the gas admission valve.
2. By completely cutting off the supply of gas during a certain number of strokes.
3. By admitting more or less of the explosive charge at a time.
4. By acting on the exhaust valve.

Sometimes two or more methods are used with the same engine, according to the greater or less fluctuations in the speed. To vary the quantity of gas within certain limits is an effectual check. But if a smaller quantity be admitted than will ignite when mixed with air, a certain amount of unburned gas passes through the cylinder, and into the exhaust. The speed is reduced because there is no explosion, but the gas is wasted. To reduce the total quantity of the charge admitted may have a similar result, and give a weak stroke. The methods usually employed, therefore, in modern engines, when the governor acts upon the gas valve, is to cut off the supply entirely for a time, when the speed is too high. Air alone being admitted, there is no explosion. The indraught of pure air certainly tends to cool the cylinder, but it also thoroughly cleanses it of the products of former combustion, and a better explosion is obtained the n time a complete charge is admitted. This is the method ad in the Otto and Atkinson engines.

The tendency in modern gas motors is to simplify construction, and reduce the number of parts. Where only two lift valves are employed, one for admission, the other for discharge of the gases, the governor is usually connected to the exhaust. Under normal conditions of speed the suction of the forward stroke lifts the admission valve, and allows the charge to enter. This valve closes as soon as compression begins, during the return stroke, and remains closed as long as the pressure in the cylinder is greater than that of the atmosphere. The opening of the exhaust valve reduces this pressure, and when the gases are all discharged the automatic admission valve rises, and a fresh charge is admitted. If the speed be too great the governor acts upon the exhaust valve, keeping it closed. The pressure in the cylinder is maintained during the return stroke, the admission valve remains closed, and no fresh charge can enter until the governor has released the exhaust.

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## CHAPTER II.

## HEAT "CYCLES" AND CLASSIFICATION OF GAS ENGINES.

CONTENTS.—Theoretical Cycle—Heat Efficiency—Classification of Gas Engines by Types.

**Theoretical Cycle.**—The word "cycle," derived from the Greek, has the same signification as circle. As applied to mechanical motors it denotes a series of operations, at the end of which the working agent returns to its original condition, as at starting. The celebrated French engineer, Sadi Carnot, was the first to use the word in this sense, and for convenience it has been retained. Engineers have agreed to designate as a "cycle" the successive operations taking place in a heat motor, though these can never form what is termed a perfect or closed cycle. In every heat motor the same phenomena are repeated each time the gas, steam, or other working agent is introduced into the cylinder. In this sense, therefore, a given cycle of operations is periodically performed in these engines. The heat generated from a certain source passes into the engine cylinder to perform the work. That portion of heat which has not been utilised in the engine is transferred to a source of cold, and the difference between these two sources (of heat and of cold) represents theoretically the heat expended in

work. A working agent is necessary, to which the heat must be imparted, and from which it is withdrawn.

The theoretical cycle imagined by Carnot, and called after him, was a perfect cycle, that is, the heat generated was employed solely in doing work, and none was wasted. The medium or "power agent," steam, gas, &c., was expanded, a piston was propelled, a given amount of work performed, and a given quantity of heat transformed into energy to produce this work. As the piston returned, it compressed the agent, restoring by compression all the heat that had been expended in work. A perfect cycle was realised, since the whole heat was thus returned to its source, and the working agent to its original condition. In practice a perfect cycle is impossible. Whatever the agent employed, it can never really return to its original condition, and all the heat be refunded, because a considerable quantity is irrecoverably lost. Much heat will escape through the cylinder walls; some will be wasted owing to imperfect expansion, passing out into the exhaust, and some will be expended in the friction of the engine. The more nearly, however, an engine approximates to the condition of a perfect cycle, and the more heat is expended in work on the piston, the greater will be the efficiency of the engine, and the higher the proportion between the useful work performed, and the heat received.

**Heat Efficiency.**—It has been shown that the higher the temperature of the mixture of gas and air in the cylinder produced by combustion, the greater the pressure, and, therefore, the greater should be the force exerted on the piston. On the other hand, the lower the temperature of the discharged gases, the more heat will be expended theoretically in work. The heat efficiency is the ratio of heat turned into work to the total heat received by the engine. In practice this efficiency is always diminished by waste of heat through various circumstances. Nevertheless, it is necessary to expand the gases as much as possible, because it is only by complete expansion that all the available heat can be utilised in doing work. If the gases are compressed by the return stroke of the piston, this heat will, theoretically, be refunded. Such a cycle of operations can, of course, be only obtained in theory, but in any case the more complete the expansion, the more the temperature and pressure of the gases discharged into the exhaust will be reduced. Less heat will be carried over from the cylinder, and more will remain to be utilised in it. Hence it is of the utmost importance to obtain as perfect a working cycle in a gas engine as possible.

**Types of Engines.**—Different authors have adopted diffe methods of classifying the various types of gas engines. bvious, but not very satisfactory, way is to divide the

horizontal and vertical. As a rule, engines for large powers are horizontal, and for small powers vertical; but in England almost all sizes are made horizontal. There is said to be less vibration than in vertical engines, and greater power is obtained for a cylinder of the same size, but many foreign makers are of opinion that the advantages of vertical engines outweigh their defects.

A more logical classification of gas motors, based on their internal working, is to divide them into engines drawing in the charge of gas and air at atmospheric pressure, and engines compressing the charge before ignition. This is the classification employed by the best authorities, and here adopted. In this way we get—

$$\text{Type} \begin{cases} \text{I. Non-compressing engines; and} \\ \text{II. Compressing engines.} \end{cases}$$

Each of these types may be subdivided into Classes *a* and *b*.

*Type* I., *Class a*, includes non-compressing motors drawing in and igniting the charge at atmospheric pressure. The force of the explosion drives the piston forward, and the return stroke expels the products of combustion. This type of engine is also made double-acting, giving an explosion or motor impulse per stroke on each side of the piston, and all the operations of admission, ignition, and expansion are effected while the piston moves once out and back again. The gases are discharged at the end of the stroke. These double-acting engines are not much used; the original Lenoir is the best example of the type.

*Type* I., *Class b*, also represents engines, chiefly vertical, which draw in and ignite the charge at atmospheric pressure. The piston is forced up from the bottom of the cylinder, and performs no work, not being connected to the crank. In the return stroke it is locked to the crank shaft, and descends only by the force of atmospheric pressure. This is the motor or working stroke. In a certain sense this class of engine is also double-acting, like Class *a*, the piston receiving two impulses per revolution; the first from the explosion of the gas below, the second from the pressure of the atmosphere above. The best representative of this type is the Otto and Langen engine. In one variety, the Bisschop, the piston is driven up with great force, but is permanently connected to the motor shaft, instead of being free during its ascent.

*Type* II. comprises all engines using compression, and like the first type is divided into two classes. *In Class a* the whole cycle of work, including compression, takes place in the motor cylinder
to effect the various operations in one
y to sacrifice one complete stroke. Com-
t the expense of power, and the piston

moves twice backwards and forwards for every explosion or motor impulse given to the crank shaft. The well-known Otto engine is a typical example.

*In Type* II., *Class b*, there is the same cycle of operations as in Class *a*, but instead of sacrificing a stroke of the motor piston, a special auxiliary cylinder is added. Admission of the charge in the pump, and expansion in the motor cylinder, are effected simultaneously; the return stroke in the pump compresses the charge, while the motor piston drives out the products of combustion, as in the Clerk engine.

There are very few engines which do not belong to either of these types. These are chiefly six-cycle engines, where the operations are similar to those described in *Type* II., *Class a*, but a third complete stroke is added, in order to cleanse the cylinder thoroughly of the products of previous combustion by what is called a "scavenger" charge of pure air. To avoid the difficulty of having only one motor stroke in six, these engines are sometimes made double-acting—that is, an explosion takes place alternately at either end of the cylinder at every third stroke. Thus, there are two impulses for every three revolutions, as in the well-known Griffin engine. The action of these different types will be fully explained later on.

It must be remembered that, in describing the to and fro motion of the piston of an engine, and its action on the crank, there are always two strokes, the forward or motor stroke, and the return or exhaust stroke. The forward or up stroke is towards the crank, the return or down stroke is away from the crank. The position of the piston corresponding to the outer dead point is when it is nearest to the crank shaft, and that corresponding to the inner dead point when it is farthest away from the crank. These terms will be used in this work.

The following table exhibits the different types and their cycles. The engines are assumed to be horizontal, except when otherwise mentioned:—

### Type I.—Non-compressing.

| | Cycle of operations. |
|---|---|
| *Class a.*<br>One explosion each revolution—one cylinder.<br>(Example, Lenoir.) | 1. Forward or *motor* stroke—admission of charge of gas and air; ignition, explosion, expansion.<br>2. Return stroke — discharge of gases. |
| *Class b* (vertical only).<br>One explosion per revolution—one cylinder.<br>(Example, Atmospheric engine.) | 1. Up stroke—admission of gas and air; ignition, explosion, expansion.<br>2. Down or *motor* stroke—discharge of gases. |

### Type II.—Compressing.

| | Cycle of operations. |
|---|---|
| *Class a.* One explosion per two revolutions—one cylinder. (Example, Otto.) | 1. Forward stroke — admission of gas and air.<br>2. Return stroke—compression.<br>3. Forward or *motor* stroke—ignition, explosion, expansion.<br>4. Return stroke — discharge of gases. |
| *Class b.* One cylinder and one pump—one explosion per revolution. (Example, Clerk.) | 1. Forward or *motor* stroke — in cylinder—ignition, explosion, expansion; in pump—admission of gas and air.<br>2. Return stroke—in cylinder—discharge of gases; in pump—compression. |

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## CHAPTER III.

## HISTORY OF THE GAS ENGINE.

CONTENTS.—Early Combustion Engines—Gas Engines by Hautefeuille, Huyghens, Papin, Barber, Street, Lebon, Brown, Wright, Barnett, Drake, and others—Use of Town Gas for Engines—The Barsanti and Matteucci Patents.

**Early Combustion Engines.**—The earliest attempts to obtain motive power from heat were made by igniting inflammable powder, and utilising the force of the explosion thus generated. As a source of energy, this combustible powder was the first agent used; it preceded the production of coal gas, or steam. Strictly speaking, cannons are the oldest heat motors, and the principles on which they are constructed are identical with those of internal combustion engines. Heat is applied to explosive powder, and the expansion of the powder furnishes the motive force to propel a ball forward. In modern heat engines a piston takes the place of the ball. In the early days of mechanical science, the energy shown in the projection of a cannon ball seemed to afford a simple solution of the problem how to obtain power and motion by heat. But the power produced by exploding powder in a cannon could not be used for practical work, because it was not generated continuously and regularly. To apply the expansive force of the gases given off during combustion, the combustible was exploded in a closed vessel, and made to act upon a piston. These early

combustion engines were the forerunners of modern gas motors, in which the power is also obtained by explosion. But though they were introduced nearly a hundred years before the first steam engine, they were soon abandoned, because it was found impossible to control the power generated. Steam was easier and safer to work with, and for more than a century explosive engines were wholly relinquished.

**Hautefeuille.**—The first to propose the use of explosive powder to obtain power was the Abbé Hautefeuille, the son of a baker at Orleans. To him belongs the honour of designing, not only the first engine worthy of the name, but the first machine using heat as a motive force, and capable of producing a definite quantity of continuous work. As such, he may be considered one of the originators of heat motors. In 1678 he suggested the construction of a powder motor to raise water. The powder was burnt in a vessel communicating with a reservoir of water. As the gases cooled after combustion a partial vacuum was formed, and the water was raised by atmospheric pressure from the reservoir. Another machine described by him in 1682 was based on the principle of the circulation of the blood, produced by the alternate expansion and contraction of the heart. Here the water was raised by the direct expansive action of the combustible gases given off by the powder when ignited. This was the first instance of a direct-acting engine, but no machine could be made strong enough to resist the spasmodic expansion of powder, as here proposed.

**Huyghens, Papin.**—Hautefeuille does not seem to have actually constructed the machines he designed; but Huyghens, who was the first, in 1680, to employ a cylinder and piston, constructed a working engine, and exhibited it to Colbert, the French Minister of Finance. The powder in this motor was ignited in a little receptacle screwed on to the bottom of a cylinder. The latter was immediately filled with flame, and the air in it was driven out through leather tubes, which by their expansion acted for the moment as valves. The piston was forced by the pressure of the atmosphere into the vacuum thus formed. This is the action shown in modern atmospheric gas engines, but Huyghens found a difficulty in getting his valves to act properly, and in 1690 an endeavour was made by **Papin** to improve upon his principle. By providing the valves with hydraulic joints, Papin contrived to make them tighter, and to obtain a better vacuum, but he found that, in spite of all his efforts, a fifth part of the air still remained in the cylinder, and checked the free descent of the piston. After various attempts to overcome this difficulty, he abandoned the use of explosive powd[illegible] and devoted his attention to steam.

**Barber.**—For more than 100 years after these early atten[illegible] all the efforts of scientific men and inventors were direct[illegible]

the study of steam, and its applications to produce power. For the time there was no other known agent that could compete with it. Gas extracted from coal had not yet been applied as a motive force in engines, and experience had shown that explosive powders were too dangerous, and too intermittent in their action, to be used with safety. The first to design and construct an actual gas engine was John Barber, who took out a patent (No. 1833) in 1791. Various circumstances contributed to the success of his invention. The steam engine already occupied an important position in mechanical science, thanks to the genius of Watt, Newcomen, Smeaton, and others. Workmen had by this time been trained, able to turn out and adjust with fair precision the different parts of an engine, though good tools were still hardly to be obtained. The distillation of gas from coal had already been discovered by Dr. Watson, though it was not till 1792 that Murdoch, a Cornish engineer,* applied it to practical use. Barber made the gas required for his engine from wood, coal, oil, or other substances, heated in a retort, from whence the gases obtained were conveyed into a receiver and cooled. A pump next forced them, mixed in proper proportion with atmospheric air, into a vessel termed the "Exploder." Here they were ignited, and the mixture issued out in a continuous stream of flame against the vanes of a paddle wheel, driving them round with great force. Water was also injected into the explosive mixture to cool the mouth of the vessel and, by producing steam, to increase the volume of the charge. Barber's engine exhibits in an elementary form the principle of what is now known as combustion at constant pressure, but it had neither piston nor cylinder.

**Street.**—The next engine, invented by Robert Street, and for which he took out a patent (No. 1983) May 7th, 1794, was a great step in advance. Inflammable gas was exploded in a cylinder and drove up a piston by its expansion, thus affording the first example of a practical internal combustion engine. The gas was obtained by sprinkling spirits of turpentine or petroleum at the bottom of a cylinder, and evaporating them by a fire beneath. The up stroke of the piston admitted a certain quantity of air, which mixed with the inflammable vapour. Flame was next sucked in from a light outside the cylinder, through a valve uncovered by the piston, and the mixture of gas and air ignited. The explosion drove up the piston, and forced down the piston of a pump for raising water. In this engine many modern ideas were foreshawdowed, especially the ignition by external flame, and the admission of air by the suction of the piston during the stroke, but the mechanical details were crude and imperfect.

* [F]irst practical application of gas to lighting purposes was in 1798 [Bol]ton and Watt Soho Factory near Birmingham, where Murdoch [was empl]oyed.

**Lebon.**—A great improvement in the practical application of gas engines was made by Philippe Lebon, a French engineer, who obtained a patent, Sept. 28th, 1799, and a second in 1801. The first was more particularly intended to describe the production of lighting gas from coal; in the latter he proposed to utilise this gas to drive a piston in an engine very similar to that designed by Lenoir, sixty years later. The inflammable gas and "sufficient air to make it ignite" were introduced separately into the cylinder on both sides of the piston, and the inventor proposed to fire the mixture by an electric spark. The machine was double acting, and the explosions of gas took place alternately on each side of the piston. The most striking peculiarity of the engine was the piston-rod, working not only the motor shaft, but through it two pumps, in which the gas and air were compressed, before they entered the motor cylinder. Lebon also suggested that the machine generating the electric spark should be driven from the motor shaft. The excellent theoretical principles on which this machine had been designed were striking at that early period, and marked a new era in gas engines. More than sixty years elapsed before the great advantages Lebon had so clearly understood, of compressing the gas and air before ignition, were fully realised. The progress of mechanical science was perhaps retarded for many years by the assassination of this skilful engineer in 1804, before he had time to perfect the details of his invention. But in any case Lebon's engine was too much in advance of the times to have achieved immediate success. The manufacture of gas from coal was still in its infancy, and it was too expensive and difficult to produce to be used for driving an engine, while electricity was at that period so imperfectly understood, that the ignition of the charge by an electric spark was alone sufficient to condemn the motor.

**Brown.**—Lebon had many imitators, especially in France, but the next to invent a practical engine was an Englishman, Samuel Brown, who took out two patents, No. 4874, in 1823, and No. 5350, in 1826. Brown's gas engines were the first actually at work in London and the neighbourhood, and also the first in which the pressure of the atmosphere was utilised as a motive power. The principle in both was the same, viz., to produce a partial vacuum in a cylinder by filling it with coal gas flames, which drove out the air; the products of combustion were instantly cooled, and the vacuum thus obtained utilised to drive a piston. Instead of explosion, combustion of the gases was obtained by lighting them by a small flame as they entered the cylinder. The temperature of the latter was reduced by a water jacket, and water was injected to help the vacuum. In his engine Brown employed two cylinders and pistons, connecte a beam. One piston was driven down by atmospheric pr at one end of the beam, while the other, connected to th

end, was simultaneously raised. Part of the air escaped through valves in the piston, and the burning gases being instantly cooled by the water injected, condensation was produced, and a vacuum formed. In his second gas engine several cylinders were used, to obtain a continuous vacuum. The working action was the same, but the air escaped through the valve covers of the cylinders, which were successively lifted. As in the other engine the gases were cooled, after combustion, by the injection of water. These engines were, however, cumbrous and difficult to work, and the expense of driving them with coal gas soon stopped their manufacture. A drawing is given in Robinson's *Gas and Petroleum Engines*, p. 105.

**Wright.**—The next improvement in gas motors was the use of a governor to control the speed, introduced by Wright in his vertical double-acting engine, patented 1833 (No. 6525). Wright's engine had one cylinder and piston, and one explosion was obtained alternately at either end of the cylinder. The piston and piston-rod were hollow, and the cylinder had a water jacket to counteract the intense heat of the double explosion. Ignition was obtained by an external flame and a touch hole. The gas and air were slightly compressed in separate reservoirs, before entering the motor cylinder; their admission was regulated by a centrifugal governor, and the richness of the mixture, or the greater or less quantity of gas passing the valve, varied with the speed. The design of this engine was carefully thought out, and its practical working details had not been overlooked, but it appears doubtful whether it was ever made.

**Barnett.**—Five years later, in 1838, William Barnett, another Englishman, took out patents for three vertical engines. These engines contained so many novel and interesting features, and anticipated in so many ways the latest improvements of modern science, that they mark an important advance in the construction of gas motors.* The first (patent No. 7615) had one working cylinder, single acting. Gas and air were drawn in and compressed by two pumps, and passed into a receiver below the motor cylinder, where they were mixed. During the down stroke of the pumps, while the charge was being forced into the receiver at a pressure of about 25 lbs. per square inch, the return stroke of the motor piston was discharging the burnt gases through the exhaust. All three pistons moved simultaneously up and down. As the motor piston reached the bottom of its stroke, a valve at the side opened communication with the receiver. At the same time a revolving ignition cock immediately above the exhaust fired the mixture issuing from the receiver, and the burning gases entered the motor cylinder

* drawing of Barnett's engine is given in the *Proceedings of the Inst. cal Engineers*, 1889.

through the admission port, and impelled the piston upwards, as the crank passed the dead point.

The conical ignition cock, two views of which are shown at Fig. 1, is well designed, and has formed the type for many similar arrangements. It consists of a hollow revolving plug, A, in a shell, B. There are two openings, *d* communicating with the outer air, and *e* facing the cylinder; the conical plug itself

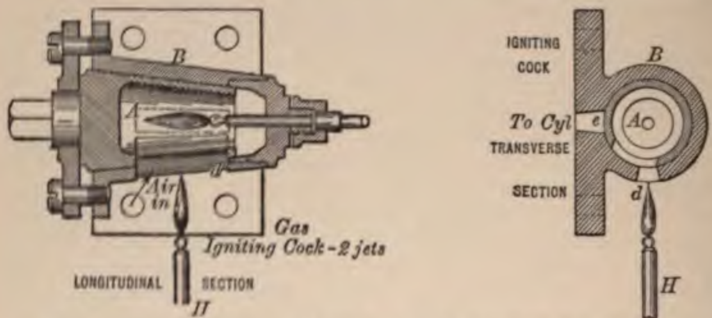


Fig. 1.—Barnett's Engine Gas Ignition Cock—Longitudinal and Transverse Section.

has only one port. At the bottom of the shell is a gas jet, which, when lighted, is in the centre of the hollow plug. As the plug revolves, the slit in it is brought opposite the port, *e*, of the shell communicating with the cylinder, and part of the highly-compressed gases pass into the hollow plug, and fire the charge. The flame itself is blown out by the force of the explosion; but, as the plug continues to revolve, the slit is brought to face port *d*, opening to the atmosphere, on the outside of which is a permanent second gas flame, H. Here the light is rekindled, each time it is brought round by the revolving plug.

Barnett's second engine was double acting, but in principle it resembled the first. The third engine in its mechanical details differed very little from the gas motors now in use, and modern inventors have found it difficult to improve upon it in theory. One defect of Barnett's former engines was that, as the receiver or charging cylinder was never swept out by the piston, a portion of the gases of combustion was not displaced by the new compressed charge of gas and air, but always remained in it. Barnett proposed to overcome this difficulty by the use of an exhaust pump; but in his third engine he abolished both pump and receiver. The gas and air were compressed in s cylinders, and delivered direct into the motor cylinde pump shaft was driven by a pair of wheels from the mo shaft, and the pumps made twice as many

piston. The engine was double acting, and the compressed gas and air were admitted alternately to each face of the piston. The action of the engine and exhaust valve was as follows:— The piston being at the bottom of the cylinder, the compressed charge below it was fired by the ignition cock in the same way as in the single-acting engine. The piston drove up before it the products of combustion from the last explosion, and discharged them during the first half of the stroke into the atmosphere, through a port in the centre of the cylinder. As this port was closed by the piston, the pressure below it fell to that of the atmosphere. The gas and air, already compressed in the pumps, were then delivered into the top of the cylinder, and still further compressed by the continued up stroke of the motor piston, together with a certain quantity of the gases of combustion left from the former charge. The mixture at high pressure was fired, and the piston driven down by the explosion, forcing out the burnt gases below it in the first part, and compressing the residuum with the fresh charge during the second part of the stroke. At the bottom of the cylinder a fresh explosion took place, and the cycle was repeated.

Barnett may justly claim the honour of having been the first to introduce compression of the gas and air in a practical shape, as now used in gas engines. Lebon, it is true, proposed to compress the mixture slightly before igniting it, but he did not work out the details, or put his method to the test of actual practice. There are three points distinguishing Barnett's from previous engines. Ignition was effected at the dead point, and gave an impetus to the crank and piston during the whole forward stroke; the gas and air were compressed before ignition; and part of the products of combustion were utilised to increase the pressure in the motor cylinder. It is generally admitted, however, that Barnett did not recognise the merit of his own suggestions. Experience has shown that compression is essential to economy in a gas engine, and ignition at the dead point is also important, but Barnett apparently used both, without realising their value. Nor did he seem aware of the difficulties of disposing of the gases of combustion, a point on which later inventors have differed so widely; for although he attempted to discharge the greater part, he evidently did not regard the presence of the remainder as affecting the explosion of the mixture. In the opinion of Mr. Clerk, insufficient expansion was the fault of the later Barnett engine, a defect which it has hitherto been found impossible to avoid in double-acting engines.

Two or three smaller engines were designed during the next twenty years, although none of them seem to have been constructed. In 1841 Johnston described a motor in which he proposed to introduce oxygen and hydrogen gas into the cylinder,

and fire them. The force of the explosion drove up the piston, and a vacuum was produced by the condensation of the gases. The same process was repeated at the top of the cylinder, and the piston was forced down by the fresh explosion, ascending and descending alternately in a vacuum. The great cost of these gases was sufficient to condemn Johnston's project of what may be called a condensing oxy-hydrogen engine.

Between the years 1838 to 1860 a large number of patents were taken out both in England and France, but most of the engines never advanced beyond the specification. Sixteen patents were granted from 1850 to 1860. Among the engines designed were—Ador, 1838; Robinson, 1843; Reynolds, 1844; Perry, 1845; Brown, 1846; Roger, 1853; Bolton and Webb, 1853; Edington, 1854, and others. A few contain novel though impracticable features, and are described below, because, as inventions, they are interesting.

**Drake.**—An ingenious gas engine was exhibited by Dr. Drake at Philadelphia in 1843; the English patent (No. 562) was taken out in 1855 by A. V. Newton. In this horizontal engine ordinary lighting gas was used, mixed with nine or ten times its volume of atmospheric air. Much care was taken to admit the mixture in proper proportions, and the supply of gas was regulated by valves controlled by a governor. The charge entered the cylinder at atmospheric pressure, and was fired by a small tube kept at white heat by an external flame. The force of the explosion drove out the piston, giving a maximum pressure of about 100 lbs. per square inch; the mean effective pressure during the stroke, with a speed of sixty revolutions, and twenty indicated H.P.,* was about 36 lbs. per square inch. The cylinder had a water jacket, and the piston was hollow. The engine was originally double-acting, but when used in America it worked single-acting only; the valves on one side of the piston were kept always open to the atmosphere. The force of the explosion was very great, and owing to defective construction was chiefly directed against the cylinder heads, shaking the whole machinery. The engine was afterwards modified, and worked chiefly with petroleum.

An important suggestion, which has since formed the basis of many successful engines, was made by Degrand in 1858. He proposed to compress the charge in the cylinder by the motor piston, but the idea was abandoned at the time, because Degrand required a large cylinder to obtain previous compression.

None of these engines worked successfully, and many were never made. One cause of their failure, which has not been much noticed by writers on the subject, was the difficu

* H.P. = Horse-Power.
I.H.P. = Indicated Horse-Power.
B.H.P. = Brake Horse-Power.

of procuring lighting gas from coal, except in a few of the large towns. The art of distilling gas was still in its infancy, and possibly few of the early inventors foresaw the day when gas would become a household commodity, as easily obtained, even in small villages, as water. Sixty years ago, it was costly and seldom available, and numerous substitutes, none of them very practical, were proposed. As gas was more extensively made it became much cheaper; engineers saw in it a new motive power, concentrated their efforts to utilise it, and finally achieved success. Another mistake made by the early inventors of gas motors was, that they attempted to supplant, instead of to supplement, the steam engine. They did not perceive the real advantages of the gas engine as a motor for small powers, but tried to make economical engines up to 20 H.P., or 50 H.P., before the constructive details were thoroughly understood. A third difficulty in constructing practical gas engines lay in the ignorance prevailing on the subject. They were designed too much on the lines of steam engines. Most of the latter were double acting, and the inventors of the day could not divest their minds of the idea that a similar method, if adopted with gas, would give the same favourable results. Experience has shown that the action of gas in a cylinder is very different from that of steam, and that gas engines must be differently designed.

**Barsanti and Matteucci.** — At about this period, however (1860), and especially after the production of the Lenoir and Hugon engines, three defects had come to be recognised as the inevitable results of an explosion at each to and fro stroke of the piston. The heat generated was so great that it had to be carried off as quickly as possible, and even with water jackets to the cylinder, parts of the engine sometimes became red hot. It was also impossible, in a double-acting engine, to compress the gas and air before ignition; and lastly expansion of the gases was greatly limited. The stroke of the piston was too short to utilise to the full the expansive force produced by the explosion, and the products of combustion were discharged at a pressure much above atmospheric. In this way, almost all the heat generated by the ignition and explosion of the gases was wasted. Many experiments were made, and many engines constructed, before it was realised that the greater the amount of heat utilised by doing work on the piston, the lower would be the temperature and pressure of the gases at discharge, and the less heat would be wasted. The next engine, invented by two Italians, Barsanti and Matteucci, showed a better knowledge of the principles of economy. In it a distinct step in advance was made, and an important principle exhibited for the first time in practice, namely, the use of a free piston, and unchecked expansion of the charge. this reason Barsanti and Matteucci's motor deserves attention

and study, though, like many others, it was not a practical working success.

In this vertical atmospheric engine, as in Barnett's first motor, the idea of a cylinder closed at both ends is abandoned. Explosion takes place at the bottom of the cylinder, the piston is free and not connected during the up stroke to the crank shaft. The motive force is exerted only during the down stroke. A vacuum being produced below the piston by the cooling of the exploded gases, it descends by the atmospheric pressure above it, plus its own weight. This is the first example of an indirect vacuum engine with free piston. Gas and air are admitted at atmospheric pressure through slide valves into the cylinder, where they are partly mixed, and fired by an electric spark. The piston is driven up by the explosion, without any check to its velocity, or to the expansive energy of the gases. Before it reaches the top of its stroke the explosive force is expended, but it is still urged upwards by the weight of the different parts in motion. It is there brought to a stand by the pressure of the atmosphere, and begins to descend; a rack on the piston-rod catches into a cog-wheel, driving the motor shaft with it in its descent, and giving the positive or useful work performed by the engine.

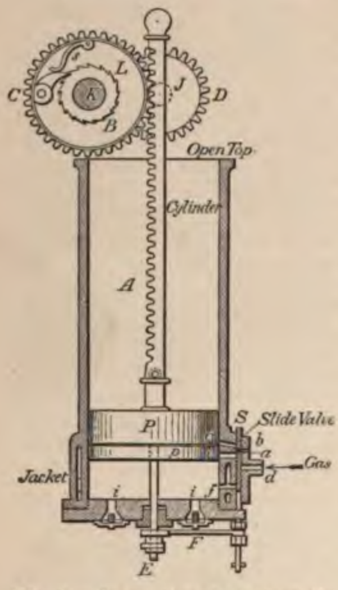

Fig. 2.—Barsanti and Matteucci's Gas Atmospheric Engine.

Two patents were taken out by Barsanti and Matteucci in England, the first in 1854, the second in 1857. In the first the free piston was supplemented by a lower auxiliary piston immediately below it in the same cylinder. An outline drawing of the engine is shown at Fig. 2. A is the cylinder and P the motor piston; *p* is the auxiliary piston, S the flat slide valve actuated by a lever, F, connected with the rod E of the auxiliary piston, which passes through the bottom of the cylinder. The crosshead at E is attached by two levers, not shown in the drawing, to the wheel D and the crank J, driven from the main shaft, but not revolving so rapidly. As soon as the free piston P reached its lowest position *p* begins to descend, and air is itted between the two pistons through the passages *a*, *b*, *c* of

the slide valve S. As the auxiliary piston descends, the slide valve is lowered with it by the lever F, the air port *a* is closed, and the gas port *d* uncovered, admitting gas to the cylinder between the pistons, through *d*, *b*, and *c*. The slide valve next shuts off *d*, when the mixture is fired by a series of electric sparks, the circuit being put on by the lever F. The piston P which has been at a stand, is now projected upwards, and *p* is forced still lower, driving out the products of combustion below it through the openings *i i* in the bottom of the cylinder. The pressure in the cylinder beneath the free piston is now below atmosphere, the valves *i i* close automatically, the channel *f* is uncovered, and as the piston rises, communication is established between the contents of the cylinder above and below the piston *p*, through *f*, *e*, and *b*. The working piston descends in the vacuum, driving out the exhaust, and the same process is repeated.

The arrangement of the catch is novel and ingenious. The rod of the free piston P carries a rack, and as soon as the piston begins to descend, the rack gears into the toothed wheel L, running loose on the main shaft K. The wheel L has a pawl C. As the rack falls, and drags L round to the right, the spring *s* presses the pawl C into the teeth of the ratchet wheel B, which is keyed on to the main shaft K, and causes B and therefore K to rotate to the right. When the piston rises, the main shaft continues to turn to the right, but the movement of the wheel L is reversed; it revolves to the left with the up stroke of the piston, and C, slipping past B, loses connection with the main shaft. To steady the motion of the engine two working cylinders and pistons were employed, driving the shaft alternately, and the flywheel also helped to regulate the speed. The rack and clutch gear form the basis of similar methods for utilising the down stroke in atmospheric engines, and have, with the free piston, been repeated with modifications in the Otto and Langen, Gilles, and others. In the Barsanti and Matteucci engine the modern slide valve was also first introduced, the main construction of which has since been retained, although the valve is often differently driven.

The second engine, patented by Barsanti and Matteucci, had the long vertical cylinder and piston with rack, but the auxiliary piston was abolished. The slide valve was worked by a valve rod, and the details were much simplified. There was an auxiliary as well as a motor shaft, both having pawls act[illegible] upon the rack. When the piston is in its lowest [illegible] slightly raised by the pawl upon the main shaft [illegible] is lifted at the same time by a smaller paw[illegible] shaft, and air admitted through an outlet [illegible] the exhaust. As the piston and slide valv[illegible] off the air, and opens the gas port. Th[illegible]

this port, the mixture in the cylinder is fired by an electric spark, and the piston driven up as before, free of the main shaft. During its descent the piston-rod engages in the wheel and ratchet on the main shaft, causing the whole to revolve during the down stroke. As soon as the pressures above and below the piston are equalised, and its descent arrested, it is caught by the other pawl, and held down, to drive out the products of combustion. The movement of the slide valve is regulated in the same way by the two smaller pawls on the main and auxiliary shafts, acting on two projections on the valve-rod. The piston having reached its lowest position, is raised by the pawls upon the main shaft, to admit a fresh charge.

In this engine a much better and freer expansion was afforded to the combustible gases than had hitherto been obtained. In fact there was no check to their expansion, except the weight of the piston, &c. But, notwithstanding its excellent cycle, this motor was never in the market, probably because the working details and the mechanism were defective. That the main lines on which it was constructed were good, is proved by the fact that they were adopted and successfully put in practice by Otto and Langen, though the German engineers appear to have designed their motor independently. The fundamental principle of the Barsanti and Matteucci engine, to utilise the whole force of the explosion in as complete expansion as possible, was excellent, and has not been improved upon. Few modern inventors have been able to approach as closely the conditions of a perfect theoretical cycle.

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## CHAPTER IV.

## HISTORY OF THE GAS ENGINE—(*Continued*).



ABOUT the year 1860 the importance of the gas engine had become widely recognised. Great as was the perfection to which steam engines had been brought, it was felt that they did not, and could not, supply the various requirements for an economical motor. The necessity for some other kind of engine had already been pointed out by Cheverton in 1826. In a letter to the Mechanic's Magazine he says—"It has long been a desideratum in practical mechanics to possess a power engine, which shall be ready for use at any time, capable of being put in motion without any extra consumption of means, and without a

loss of time in its preparation. These qualities would make it applicable in cases where but a small power is wanted, and only occasionally required. They are so numerous, and the consequent saving of human strength would be so great, that the advantages accruing to society would be immense, if even the current expense were much greater than that of steam." No words could better describe the present advantages of the gas engine.

**Application.**—In the history of gas motors three periods may be distinguished—1. Invention; 2. Application; 3. Theoretical and practical improvement. The first, the period of invention, was over. Hydrogen, inflammable powder, and other explosives were no longer used in engine cylinders, and gas was already recognised as the most suitable medium, next to steam, for utilising heat as a motive power. In the construction of the gas engine, much had been achieved by mechanical ingenuity. All the parts had been designed, and the details thought out. Scarcely a single improvement has been suggested in modern engines, which may not be found in the drawings of Lebon, Barber, Street, Barnett, and others. In the words of Professor Witz—"The gas motor had been invented; the problem was how to make it a working success." It is here that we enter on the second period, of Application. That time, too, has now passed. Practical experience has long been brought to bear on the construction of the gas engine, but the maximum utilisation of the heat is still a problem of the future.

**Lenoir.**—From this point of view, the honour of having invented and introduced the first practical working gas engine justly belongs to Lenoir. His specification set forth no new features, but he was able not only to make his engine work, which no one had hitherto succeeded in doing, but to work rapidly, silently, and, as at first supposed, more economically than steam. Cost and space were reduced by the absence of a boiler, and nothing could apparently be simpler, nor better suited to drive machinery of every kind, than the new motor. Its success was undoubted, and every one was eager to see it. The partisans of Lenoir loudly and confidently affirmed that the reign of steam was over, and that it would be immediately superseded by gas. The economy attributed to the Lenoir motor, and exaggerated by report, increased its popularity. Although made at a time when very little was known of the theory of the gas engine, and its action was imperfectly understood, the new motor was credited with an economy in the consumption of gas which inventors, after thirty years of study and experience, have hardly been able to realise.

[illegible] took out his first patent in France Jan. 24, [illegible] No. 335, Feb. [illegible] The engines were made by Marinoni, a French engineer [illegible]

undoubtedly contributed to their success. During the first year one was constructed of 6 H.P. and another of 20 H.P., and so great was the demand that, in five years, between three and four hundred motors were made in France, and a hundred in England. This is a large number, considering that the gas engine was still on its trial. A Lenoir engine was used to propel a boat on the Seine, and for twenty years water has been pumped by another at Petworth. The construction was undertaken by the Reading Iron Works in England, and the Compagnie Lenoir at Paris. In 1863 the patent of the latter was acquired by the Compagnie Parisienne de Gas.

The usual reaction from such undue praise and indiscriminate adoption of the new engine followed. The chief cause of its sudden fall in popular esteem was the discovery, that it consumed much more gas than it was said to do. Some of the advocates of the new motor claimed a consumption of 31·7 cubic feet of gas per H.P. per hour; others instituted a comparison with the steam engine, to the disadvantage of the latter. Thus, it was asserted that the cost of working a 4 H.P. steam engine in Berlin was 6s. 6d. per hour; for a Lenoir engine of the same power it was said to be about half. These figures were greatly exaggerated. In practice the Lenoir engine consumed from 88 to 105 cubic feet of Paris gas per H.P. per hour. A brake experiment gave a mean of nearly 106 cubic feet, and this was about the average consumption for small powers. The quantity of water required for the cooling jacket was considerable. The heat generated was so great that, unless the engine was copiously oiled, the working parts were injured, and it was brought to a stand. Hence it was sarcastically said that "the Lenoir motor did not require heating, but oiling."

In the reaction which now set in most of the Lenoir engines were at once abandoned; some were broken up, and a few even turned into steam engines. This sweeping condemnation was hardly justified. The engines possessed many advantages, which were as completely overlooked as their defects had been at first. They were easy to transport, to fix, and to set to work, and, when constructed for small powers, were very useful in many cases for superseding manual labour. If the consumption of gas was heavy, the original cost of construction was said to be less than that of a steam motor. The engine could be started at a moment's notice, and when not running, no expense for gas was incurred, while it has hardly been surpassed for silent, smooth, and regular working. But these were not the chief merits of the Lenoir engine. It was the first to compete with steam for small powers, and to familiarise the public with the idea of obtaining motive power from gas. The advantages of these otors were so great and so patent that, when the Lenoir was dually superseded, it was replaced by other engines driven by

gas. Its very defects acted as a stimulus to fresh efforts, and kept the subject before the minds of inventors. Once accustomed to the easy action of a gas engine, in which it was only necessary to turn a valve on the gas main, and another on the water supply, to set the machine in motion, many people refused to return to the laborious process of generating steam in a boiler.

Lenoir was himself fully alive to the faults of his engine, and continually studied to overcome them, but he started from a wrong basis. He attributed the extravagant consumption of gas to the rapidity of explosion, which affected the action of the engine injuriously, by producing a sudden rise and fall in the pressure. In common with later inventors, he endeavoured to diminish the force of the explosion, and to obtain a slower combustion of the gases by stratification, and in a second patent, No. 107, January 14, 1861, he also proposed to inject a little water into the cylinder. In his opinion it would help to lubricate the engine, take up by evaporation some of the heat developed, and, above all, cool the charge and retard explosion. The injection of steam into a gas engine cylinder has since been often suggested, and put in practice, without producing any real economy—its advantages and defects will be considered later on. Lenoir himself does not seem to have carried out his proposal.

The much vaunted and much abused Lenoir gas engine resembled in construction a double-acting horizontal steam engine, and the gas was ignited electrically. Gas and air were admitted at both ends, drawn in by the piston during the first part of the stroke, and then fired and expanded. Admission of the charge was cut off, either at half stroke or a little later. As ignition with the electric spark was not always instantaneous, it occasionally happened that the piston had passed through a considerable portion of the stroke before explosion occurred, and incomplete expansion was the result. The cylinder, both covers, and the chamber into which the gas was admitted, were water-jacketed, and the circulating water was used over and over again.

In the original drawing of the engine, shown at Fig. 3, A is the motor cylinder, in which is the piston P. The piston-rod works the connecting-rod C, and crank shaft K, through the crosshead D. Two eccentrics, G and H, on the crank shaft, work two flat valves, S and $S_1$, on either side of the cylinder. The slide valves, S S, admit gas and air into the cylinder, and those at $S_1$ $S_1$, allow the products of combustion to escape. The latter each contain one exhaust port; and these are brought into line with the exhaust openings shortly before the end of the stroke, to let out the gases of combustion, and close over them as the fresh mixture enters. Through the exhaust ports the

gases pass into a discharge pipe, and thence into the atmosphere. The slide valves, S S, perform the functions of admission and distribution, and the two chambers, L L, are filled with gas.

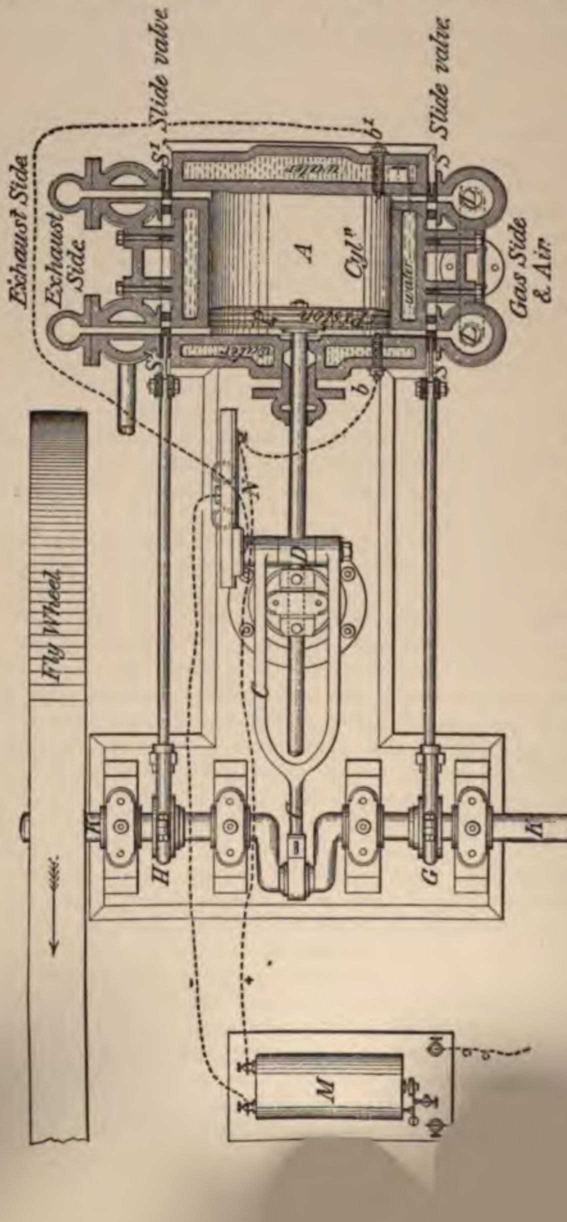


Fig. 3.—Lenoir Horizontal Engine.

These valves are made with small cylindrical holes $\frac{1}{12}$ inch in diameter, alternating with larger apertures $\frac{1}{4}$ inch by $\frac{1}{2}$ inch diameter. The gas enters from L through these holes, while the air is admitted through the ends of the slide valves, which are open to the atmosphere, and passes through the apertures in the proportions of about 1 of gas to 12 of air. This arrangement of comb-shaped grooves and passages is continued throughout the whole thickness of the slide, and the effect is to cause the gas and air to flow to the cylinder in separate streams. By thus forcing them to enter without mingling, a better stratification of the charge was supposed to be obtained. Lenoir's idea seems to have been that the ignition flame would be propagated from one stratum of gas to the next, through the dividing layers of air, but this appears doubtful, and it has been questioned whether any real stratification of gas and air takes place. At either end of the cylinder is a small projection at $b$ and $b_1$, to which wires are attached from the coil and electric battery, M.

The action of the engine is as follows:—The exhaust valves being closed when the piston is at the extreme end of the stroke, as shown in the drawing, the energy of the flywheel is sufficient to carry it forward. The air port, which is very large to prevent throttling, is already slightly open, the gas valve now opens, and

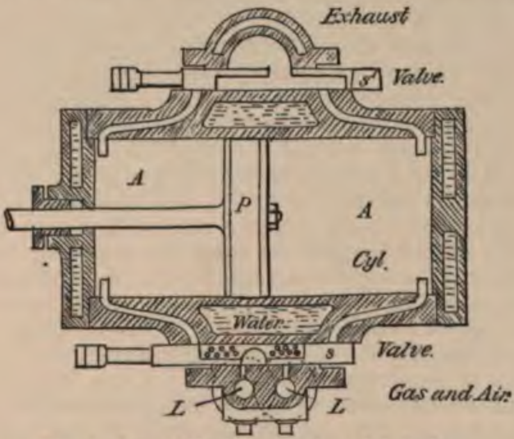


Fig. 4—Lenoir Engine—Section of Cylinder.

the charge is mixed in the main port of valve S before being drawn into the cylinder by the forward stroke of the piston. Meanwhile the pressure on the other side of the piston has been reduced to that of the atmosphere. Before the admission valve is completely closed the electric spark fires the mixture, and the piston is thus propelled forward to the end of the stroke, the

pressure rising to 5 or 6 atmospheres, but the action of the water jacket cools the cylinder, and reduces the pressure. The exhaust valve has a slight lead, and opens a little before the end of the stroke, allowing the gases of combustion to escape at a pressure of 1·5 to 1·8 atmosphere. The same process is repeated during the return stroke. A certain proportion of the gases of combustion are always left in the cylinder, but their pressure is low, and the clearance spaces are very small. The temperature of the escaping gases is given by Professor Schöttler at about 200° C. In an experiment by Tresca it was 220° C.

Fig. 4 gives a sectional plan of the cylinder, in which the admission of gas and air are slightly modified; the parts are lettered as in Fig. 3. Here the main admission port is open to the atmosphere, and is covered with a perforated brass plate, which extends downwards, so as also to cover the gas port. As the gas enters, it is forced to pass up and down through small holes in the metal plates, and to mix thoroughly with the air before entering the main port, but this arrangement, like that already described, was not found to work quite satisfactorily.

Like most of the early gas engines, the Lenoir was ignited by an electric spark, as shown at M, Fig. 3. A battery with two Bunsen cells, connected by a Ruhmkorff induction coil, and an electric hammer, produces a continuous stream of sparks. The contact maker N is in connection with the crosshead D, and piston-rod, through which the negative current passes, and the mass of the engine is negative. The positive current passes through wires insulated in porcelain tubes, leading from the two ends of the contact maker to the two projecting points, $b$ and $b_1$, at each end of the cylinder. Contact is formed alternately between them by a projection moved to and fro by the crosshead. Although carefully designed, this apparatus was open to some of the usual defects of this system of ignition; the points occasionally missed fire, and the spark was retarded, or failed.

The speed of the engine was regulated in the ordinary way by a centrifugal governor acting on the gas admission valve, and the supply of gas was wholly cut off, as soon as the speed exceeded the normal limits. The oiling was always defective. Ordinary lubrication by hand was at first used, but this was soon found insufficient to counteract the great heat generated in a double-acting gas engine. The piston frequently became red hot and heated the incoming charge *before* ignition, a defect which later inventors have endeavoured always carefully to avoid; and the temperature was so high that, unless frequently and copiously oiled, the engine would not work.

It is always less difficult to start a non-compressing gas engine fired electrically than a compression engine, and the Lenoir motor was very easily set in motion. The flywheel was tur
y hand, and the piston moved forward, drawin the exp

mixture. At the same moment electric contact was established, a spark fired the charge, and the explosion drove out the piston over the dead point, after which the engine worked automatically.

The earliest trials on record of any gas motor are those made by Tresca in 1861 on the Lenoir engine. The first experiments were on an engine of ½ H.P. with a speed of 130 revolutions per minute. The proportion of gas to air was one-tenth, the maximum pressure obtained 4·87 atmospheres, the consumption of Paris gas was 112 cubic feet per H.P. per hour. In a second trial of a 1 H.P. engine, the quantity of gas used was reduced to 96 cubic feet per H.P. per hour, or about four times the average present consumption. The maximum pressure in the cylinder was 4·36 atmospheres, number of revolutions 94, and the proportion of gas to air 1 to 7½. In both engines more than half the total heat was carried off in the water jacket, and Tresca calculated that only 4 per cent. was utilised in useful work, the remainder being discharged with the exhaust gases. The average consumption of oil was about ·10 lb. per hour. Other experiments were made by Lebleu, Eyth, and Auscher, and an important trial was carried out by Mr. Slade in America. The engine tested was about 2 H.P., and ran at 45 and 50 revolutions per minute. The maximum pressure in the cylinder was 63 lbs. above atmosphere; the consumption of gas was not determined. Fig. 5 shows an indicator diagram of the Lenoir engine.

Twenty-five years later Lenoir, who was incessantly endeavouring to perfect his invention, brought out a single-acting compression engine, using Beau de Rochas' four-cycle. It will be described among modern motors.

The success of the Lenoir engine produced a host of imitators and rivals, several of whom set up a prior claim to the invention.

Fig. 5.—Lenoir Engine—Indicator Diagram (Slade).

Reithmann, a watchmaker at Munich, declared that he had designed an engine similar to Lenoir's, for which he had taken out a patent, Sept. 11, 1858. It was described in the "Bayerische Kunst und Gewerbeblatt," but, if ever made, it never reached a practical stage. A more formidable opponent was Hugon, the Director of the Paris Gas Company, whose original patent also dates from Sept. 11, 1858. It is certain that Lenoir worked ependently, and that his invention as a practical engine was st in the market.

**Hugon.**—Hugon's vertical gas engine did not appear till 1862. His original intention, as stated in his first patent, was to construct an atmospheric engine and utilise a vacuum. He abandoned it in favour of a direct-acting engine similar in principle to Lenoir's, which he patented in France, March 29, 1865 (No. 66,807). In this engine Hugon introduced several novelties and improvements. Flame ignition was substituted for electricity, and a small quantity of water was injected into the cylinder at every stroke, to cool and lubricate it, and to economise the consumption of oil. The arrangement of the slide valves, although complicated, was ingenious. The flame to ignite the charge was carried to and fro in a cavity inside the valve, and Hugon's engine afforded the first practical illustration of this method of ignition, afterwards so generally used. The defects of Lenoir's engine were the great heat generated, retarded ignition, and insufficient expansion of the charge. These faults Hugon hoped to avoid by flame ignition and the injection of water, and it cannot be denied that his engine was superior in economy, and in certainty and rapidity of explosion. Firing the gases by a permanent flame was an improvement on electricity as then employed, but the consumption of gas was still very large. The engine did not find much favour, even in France, nor supersede the Lenoir to any great extent, though it worked smoothly and, except from the economical point of view, satisfactorily

In this vertical, single cylinder, double-acting engine, air and gas are admitted, as in the Lenoir, on both sides of the piston at atmospheric pressure. The piston P and piston-rod in cylinder A drive the shaft through a forked connecting-rod and crank, as shown in Fig. 6, taken from Schöttler's* careful description of the engine. An eccentric on the same shaft works the rubber gas reservoir C, from which the gas is pumped under slight pressure through the pipe $a$ to the cylinder. A smaller gas reservoir, D, supplies gas for the ignition flames. The valve rod, actuated by a second eccentric on the crank shaft, works the two admission valves, S and $S_1$. A small pump, B, is driven from it, and injects water into the cylinder through the supply pipe $d$ and the small openings $d_1$ and $d_2$. The main slide-valve S has five openings, $e$ and $e_1$, the igniting ports containing the two gas jets for lighting the mixture at each end of the cylinder; $g$ and $g_1$, the admission ports which receive the mixture of gas and air from the tube $a$, through the openings in the auxiliary slide $S_1$; and $h$ the exhaust valve, discharging through K into the atmosphere. In the second and smaller slide valve, $S_1$, there are only two ports for opening communication between the main slide valve and the gas reservoir C. By the action of this slide valve the sudden admission and cut off of the slide are

* Schöttler, *Die Gas Maschine*, p. 23.

obtained, which form a principal feature of the Hugon engine. The valve is driven by the same valve-rod as the valve S, through a pin working in a slot; $f$ and $f_1$ are permanent gas jets to rekindle the flame at $e$ and $e_1$, when blown out, as it is each time, by the force of the explosion. There are two main ports, serving alternately for admitting the charge to the cylinder and igniting it, and for discharging the gases of combustion into the exhaust; this arrangement has since been altered.

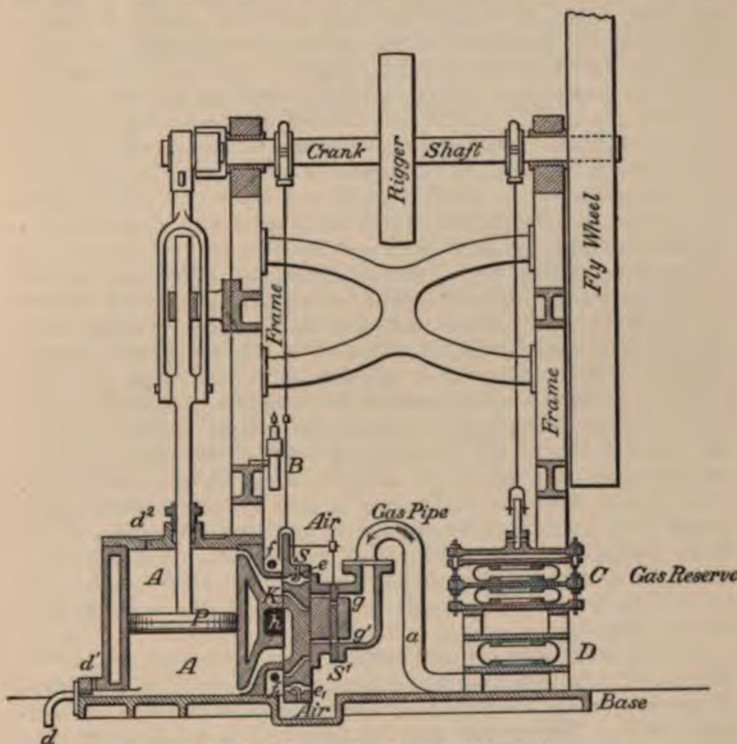


Fig. 6.—Hugon Gas Engine—Vertical.

The action of the engine is as follows:—When the piston is at the top of its stroke and begins to descend, the principal slide valve S is driven down, and the port $g$ comes immediately opposite the upper main cylinder port, forming a connection between it and a port in the outer slide valve $S_1$, admitting gas and air from C through $a$. At this part of the stroke, the position of the slide valves is the following:—The light at $e$ is in process of kindling by $f$, $g$ is opening on to the main port, while at the ... of the piston the products of the last explosion are dis-

charging through $h$ into the exhaust. The port $g$ being much smaller than the main port, the supply of gas and air through $S_1$ is soon cut off, but the communication of $g$ with the main port is still open when the slide is suddenly driven down by the movement of the eccentric on the shaft. The gas flame $e$ is brought opposite the inflammable mixture, and spreads through it, and back into the admission port. Explosion takes place when the piston has passed through about four-tenths of the stroke, and drives it down through the remainder. The piston and slide valve now begin to rise, and the same process is repeated at the lower end of the piston and cylinder. As, however, the valve in its upward progress must again cross the admission passages in slide $S_1$ before reaching the top of the cylinder, gas and air would be admitted at the wrong moment, and the rapid admission and cut off could not be obtained unless this valve were closed. It is driven down by the pin projecting from the main valve, which catches and carries it in the same direction. A spring then holds it in position, and does not release it until the slide S has begun to return.

The main ports, the clearance spaces at either end of the cylinder, and the small admission ports make up together a space in which about 30 per cent. of the total charge remains after combustion, instead of being discharged by the piston during exhaust. At the moment of ignition, this percentage of burnt products is much weaker than the fresh explosive mixture of gas and air. The incoming charge, cut off almost immediately by the down stroke of the piston, and brought directly after into contact with the flame, is easily and instantaneously fired. Explosion is far more rapid than in the Lenoir engine, and a longer time is afforded for expansion, and for the dilution of the fresh charge with the products of combustion. The explosive action being much surer, weaker mixtures can be employed, and in some of the experiments the proportion of gas to air was as low as 1 to 13·5.

The speed in the Hugon engine was regulated, as in the Lenoir, by a governor acting on the gas valve, and the admission of gas was entirely suppressed, when the velocity exceeded certain limits. The engine was lubricated in a similar way to a steam engine, but there was not the same necessity as in the Lenoir for a continual use of oil, because the water injected into the cylinder partly supplied its place. The motor was easily started by lighting the external and internal gas flames, and giving a few turns to the flywheel.

In 1866 and 1867 Tresca made two experiments in France on a 2 H.P. Hugon engine. In the first the speed was 53 revolutions, and the maximum pressure in the cylinder 3·27 atmospheres. The temperature of the discharged gases was 186° C., and the gas consumption 92 cubic feet of Paris gas per

H.P. per hour. In the second experiment the highest mean pressure was about 3·8 atmospheres, the temperature of the exhaust gases 190° C. The gas consumption was about 77 cubic feet per H.P. per hour, not including that used for the ignition flame. In an experiment made by Mr. Clerk on a ½ H.P. engine,

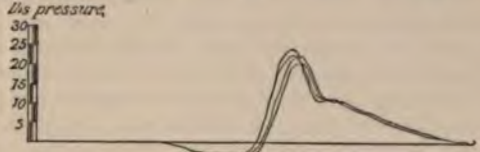


Fig. 7.—Hugon Engine—Indicator Diagram.

the maximum pressure was 25 lbs. per square inch, and the speed 75 revolutions per minute. Fig. 7 gives an indicator diagram of this trial.

**Siemens.**—About this time the subject of heat motors engaged the attention of Sir William, then Dr., Siemens, and he took out several patents for gas and hot air engines. His regenerative engine will be described in Part II. Although continually working on this subject, he does not appear to have constructed any engines, being so much occupied with other matters.

A few years later, a gas engine was brought out by Messrs. Kinder & Kinsey, closely resembling the Lenoir, but presenting no new features. The consumption of gas was said to be about 70·5 cubic feet per H.P. per hour.

The defect of both the Hugon and Lenoir engines was the large consumption of gas in proportion to work done. This extravagance checked the sale of these engines, and they ceased to be extensively made, even before others had been invented to take their place. Their failure was attributed to want of stratification. The gases were supposed not to be properly mixed, and it was hoped, by altering the arrangement of the valves through which they entered the cylinder, to remedy the defect. Inventors long thought it possible to distribute the admission of the charge in such a way, that the gas and air were introduced either in separate layers or thoroughly mixed. Both Lenoir and Hugon were of opinion that the shock given by the explosion was too violent, and needed to be weakened. These erroneous notions were gradually abandoned, and the real reasons of the want of economy were at last perceived, namely, insufficient expansion, and the absence of compression.

**Schmidt—Million.**— 1861 Gustave Schmidt, in a paper
f German Engineers,* declared that
d be obtained, greater expansion,

tscher *Ingénieure*, 1861, p. 217.

and better transformation of the heat of combustion into work, if the gas and air were previously compressed to two or three atmospheres. In the same year Million either re-discovered or was the first to apply practically Lebon's and Barnett's idea of previous compression of the gas and air. He took out an English patent, in which he proposed, like Barnett, to compress the mixture before admission by a separate pump, using the first part of the forward stroke to draw it into the cylinder. This idea he afterwards abandoned in favour of introducing the compressed gas and air, at the dead point, into a space at the working end of the cylinder, called a cartridge. Ignition followed, and the whole forward stroke of the motor piston was utilised in expansion. Million's proposals helped to develop the theory of the gas engine, but he does not seem to have put them into practice.

Thus the principle of compressing the charge of gas and air in an engine before ignition had already been foreshadowed, when a very remarkable descriptive patent upon the subject appeared in France in 1862 by M. Beau de Rochas. Hitherto the construction of gas engines had not been designed and worked out on a scientific basis. Inventors did not fully understand the effect of the different operations they proposed to carry out. They were ignorant of the reason why one engine gave more economical results than another, and what methods should be adopted to control the extravagant consumption of gas. They were all ready to recognise, without being able to remedy, the defects of their engines. Nor were study and perseverance wanting. Many of the earlier gas motors were the result of much labour and repeated experiments, and failed only for lack of a scientific comprehension of the subject.

**Beau de Rochas.**—The real reasons of the uneconomical working in the Lenoir and other motors were want of compression, incomplete expansion, and loss of heat through the walls. In both the Lenoir and Hugon engines the pressures in the cylinder were always low and difficult to maintain, and this showed that the pressure generated by the explosion alone was insufficient, and must be increased by previous compression of the charge. Time was also lost in obtaining an explosion, and the heat, applied too late to the gas, was speedily dissipated, some of it going to heat the jacket water, and some being discharged at exhaust. M. Beau de Rochas, a French engineer, was the first to formulate a complete theory of the cycle of operations which ought to be carried out in a gas engine, to utilise more completely the heat supplied. Four conditions were laid down by him as essential to efficiency.

I. The largest cylindrical volume, with the smallest circumferential surface.

I. Maximum speed of piston.

III. Greatest possible expansion.

IV. Highest pressure at the beginning of expansion.

These working conditions are now generally admitted to be necessary, but at that time they created a revolution in the study of the gas engine. The first shows the reason why the consumption of gas was so much greater in small, as compared with larger engines. On this subject Mr. Dugald Clerk says, "As an engine increases in size, the volume of gaseous mixture used increases as the cube, while the surface exposed only increases as the square; so that the proportion of volume of gaseous mixture used to surface cooling is less, the larger the engine."

In the second and third conditions increased expansion and speed are insisted on. It was already known, or at least surmised, that unless the gases were as completely and quickly expanded as possible, much of the energy generated in the explosion was wasted. Only a small proportion was expended on the piston in doing work, and the gases escaped at too high a pressure. It was evident also, since a small cylinder wall surface was desirable, that the more rapidly the piston performed its stroke, the less time were the hot gases exposed to the action of this surface. "Other things being equal," says Beau de Rochas, "the slower the speed, the greater the cooling." Moreover the higher the speed of the piston, the more rapid and therefore the more perfect will be the expansion.

In Beau de Rochas' fourth condition a principle was embodied which contains the essence of the question, and the true secret of economy in a gas engine. The utilisation of the elastic force of the gases by prolonged expansion depended upon the high pressure of the charge, and this pressure could not be realised unless the gas and air were compressed previous to ignition. Compression was to be effected while the gases were cold, and the heat thus applied prolonged the expansion by increasing their pressure. By thus compressing the particles, an originally larger volume of the charge, containing more gas, can be introduced per stroke into the cylinder, and the pressure of explosion thus considerably raised. The advantages of compression are shown by the fact that the greater the pressure, and the more instantaneous the admission, the greater the economy.

**Beau de Rochas' Cycle.**—To obtain these results Beau de Rochas considered it necessary to use one cylinder only, first, that it might be as large as possible, and secondly, to reduce the piston friction. In this cylinder the following cycle was to be carried out in four consecutive piston strokes:—

I. Drawing in the charge of gas and air.

II. Compression of the gas and air.

III. Ignition at the dead point, with subsequent explosion and expansion.

IV. Discharge of the products of combustion from the cylinder.

By the addition of the important principle of ignition at the dead point, the crank obtained the benefit of the impulse communicated by explosion and expansion during the whole of a forward stroke. This was not, however, the object specially aimed at by Beau de Rochas. He proposed to compress the gases to such an extent, that they ignited spontaneously at the dead point. The principle has since been adhered to in almost all modern gas engines, though it has generally been found impossible to obtain ignition of the gases by compression only. Each of the four operations generally requires one stroke of the piston, though in some cases compression is obtained by a separate pump.

This cycle, known as the four-cycle of Beau de Rochas, is the one now chiefly used in gas motors. It differs from that of Carnot because it is not a perfect or theoretical, but a practical, cycle. Many improvements have been effected in the mechanism of the gas motor, but they have all been founded on the sequence of operations and the working conditions described by Beau de Rochas. Next to compression, the most valuable innovations introduced by him were, carrying out all the operations in a single motor cylinder, and ignition at the dead point. But like many other scientific innovators, Beau de Rochas was in advance of his time. Fifteen years elapsed before what Professor Witz aptly calls "the programme traced of what ought to be attempted" was actually adopted, although now, thirty years after, its merit is universally recognised, and his cycle employed.

An award of 3,000 francs was presented to the veteran worker by the Société d'Encouragement pour l'Industrie Nationale in recognition of his valuable labours to advance the knowledge of the gas engine, and one of 2,000 francs by the Académie des Sciences. The "Société des Amis des Sciences" also assigned him a pension of 500 francs. M. Beau de Rochas died in 1892.

A translation of that part of his patent which relates to gas engine cycles will be found in the Appendix.

# CHAPTER V.

## HISTORY OF THE GAS ENGINE—(*Continued*).

CONTENTS.—The Otto and Langen Engine—Engines by Gilles, Hallewell, Brayton, and Simon—Ravel's Rotatory Engine—Ravel's Oscillating Engine—Foulis's Horizontal Engine.

THE construction of gas engines was meanwhile developed in a different direction to that indicated by Beau de Rochas. As it was seen that the expansion in the engines hitherto made was insufficient, an attempt was made to improve it by employing a free piston, giving in theory unlimited expansion. At the Paris Exhibition of 1867 the attention of scientific men was drawn to an engine patented by MM. Otto and Langen in 1866, and apparently of a new type, though it was really constructed on the same lines as that of Barsanti and Matteucci. It seems doubtful whether this new engine was more or less copied from the Italian's atmospheric motor, or whether the Germans worked independently. In any case they succeeded in making a practical engine, based on a principle which, owing to some mechanical defect in working it out, had been relinquished.

**Otto and Langen.**—In their main features the two engines were identical. At that time the idea was prevalent that the failure of the Lenoir and Hugon engines was due to the slow movement of the piston after ignition. Scientific men were agreed that the energy generated by explosion was rapidly diminished by the cooling action of the walls; if therefore expansion was retarded, much of the force obtained was dissipated. In an earlier patent taken out in 1863, the inventors of the Otto and Langen engine say—"Experience has shown that the interval of time which elapses between the heating and consequent expanding of the gases, and the subsequent cooling and consequent contraction, is but a very short one, and, therefore, in applying the expansive force of such heated gases as motive power, unless they are allowed to expand very rapidly—immediately after combustion has taken place—a great portion of the heat which should have produced expansion will be absorbed by the cylinder of the en consequently a great portion of the motive power wi Hence, the principle of their engine was to obtain t and complete expansion possible after explosion. this idea was right, but the mechanical difficult out have [illegible] completely overcome

construction of the engine was continued for some years, it was eventually given up.

At the time of its first appearance, the Otto and Langen was the most economical engine till then introduced. Its consumption of gas, always comparatively low, was ultimately reduced to about 26 cubic feet per H.P. per hour, a quantity not greatly in excess of good modern gas engines. About 5,000 motors were constructed in ten years, and though never popular in France, the engine was at one time in great demand in England and Germany. As a practical working motor it was not satisfactory, but it marked an epoch as the first single-acting engine, and the first in which economy in consumption of gas was realised as a consequence of better expansion. It was, however, large for the power generated, noisy and irregular in action, and the very rapid ascent of the piston caused so much vibration, that it could only be used for small powers.

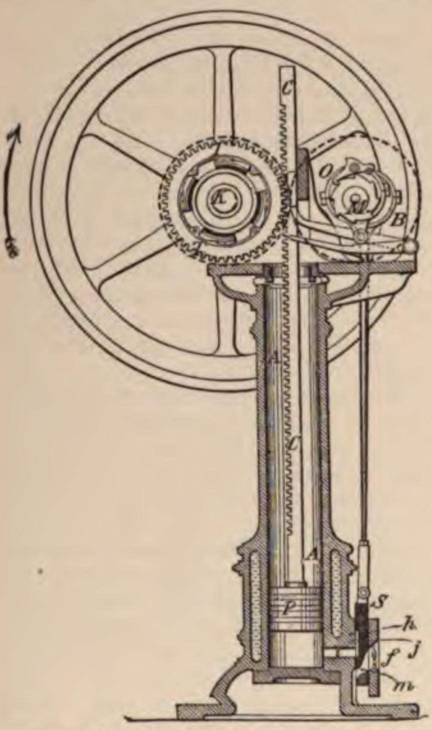

Fig. 8.—Otto and Langen Vertical Engine—Transverse Section.

**Otto and Langen, two Pistons.**—In the patent taken out by Otto and Langen in 1863 the principles they intended to work upon were set forth. They proposed to construct an engine with a vertical cylinder open at the top, containing two pistons and piston-rods, one above the other. By having two pistons it was intended to break the force of the explosions, for the idea had not yet been abandoned that the shock was injurious to the efficiency of the engine. The two pistons being at the bottom of the cylinder, the momentum of the flywheel raised he upper piston and rod, which were hollow. The force of e explosion then drove up the lower solid piston through the her, the air in the cylinder being forced out through valves at

the top of the hollow piston; both pistons descended together in the vacuum formed below them. This design presented various difficulties, and the inventors soon relinquished it, and exhibited for the first time at the Paris Exhibition of 1867 their well-known atmospheric engine.

**Otto and Langen, Single-Piston Atmospheric Engine.**—Fig. 8 gives a sectional elevation of this engine. A is the long vertical cylinder, surrounded at the bottom with a water jacket, and open at the top to the atmosphere. P, the piston, is shown almost at the end of the down stroke. C is the rack in lieu of a piston-rod, gearing into the toothed wheel T on the main shaft K. The slide valve S, worked by an eccentric, O, admits the gas and air, which are ignited by a flame in the slide valve cover, and also discharges the products into the exhaust pipe. There are two eccentrics side by side, O and B; both are connected to the auxiliary shaft M during the down stroke, but run loose on the up stroke of the piston. In the same way the wheel T, which is also free of the shaft during the up stroke, becomes wedged to it by an ingenious clutch arrangement as the piston descends. The action of the Otto and Langen engine necessitates the use of three special mechanisms, the friction coupling or clutch gear, on the outer wheel T of the main shaft, the device for lifting the piston to admit a fresh charge, served by eccentric B, and the valve motion driven by eccentric O.

The violence of the explosion in a free piston engine is so great, that much care is necessary to make the clutch act freely and instantaneously. At the moment when the movement of the piston is reversed, the whole energy of the engine being stored up in it, the least recoil might result in an accident. This was one reason why the Barsanti and Matteucci engine failed; the ratchet and pawl were not sufficiently prompt in action. The clutch gear of the Otto and Langen engine, shown at Fig. 9, was the result of careful study, and formed one of the most ingenious parts of the engine. Upon the main shaft K there is a circular disc, *a*, which is solidly keyed to it, and carries on its outer edge at *e* four steel wedge-shaped slips or projections. The inner rim of the outer toothed wheel T is hollowed out in four places at regular intervals, just below the bolts *d*, and corresponding to the steel wedges *e* upon the disc *a*. In each of the grooves thus formed are three small cylindrical rollers. The main shaft K revolves always in the direction of the hands of a clock. When the piston flies up with the force of the explosion, and drives round the toothed wheel T in the opposite direction, the rollers run loose in the open space in the wider part of the hollows, and no pressure being exerted on the wedges *e*, the connection between the main shaft K and the rack, piston, and outer toothed wheel T is severed. The piston having reached the end of the up stroke, begins rapidly to descend (motor stroke), the motion

of T is reversed, and it also revolves in the same direction as the motor shaft. The rollers are driven forward into the narrowest part of the space, and wedged against the steel slips *e*, which grip the solid disc *a*, and the whole mass from T to K is driven round in the direction of the descending piston. The cooling of the gases below the piston forms a vacuum, but this is counteracted near the end of the stroke by the opening of the exhaust. Slight compression of the gases of combustion takes place at the bottom of the cylinder, and the motion of the piston is slackened. The toothed wheel T, therefore, revolves more slowly than the main shaft and disc *a*; the rollers run back, and loosen their grip of the wedges, and before the piston has reached the end of the stroke, the motor shaft is again disconnected.

The working of the eccentrics driving the slide valve S is also shown at Fig. 9. The valve is somewhat similar in principle to

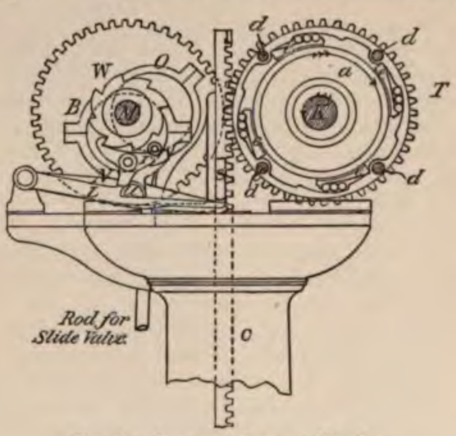


Fig. 9.—Otto and Langen Engine.

Hugon's flame ignition valve, but more simple, as only one ignition per up stroke or per revolution is required. There is one main port, *i*, Fig. 8, leading to the cylinder, and just above it are two small openings, *h* and *j*, for admitting the gas and air. In its lowest position the slide valve port forms a communication between *i* and the atmosphere, the exhaust outlet in the valve cover being closed by a flap valve, which is lifted only when the pressure in the cylinder is greater than the atmosphere—that is, when the piston has nearly reached the bottom of its stroke. The products of combustion being thus discharged, the slide S worked by the eccentric O begins to rise, and the piston with it, lifted by the other eccentric B; gas and air enter through *j*, *h*, in the proportions of 9 to 1, mix and pass through to the cavity . Communication is now made between *m* and the outer per-

manent flame *f*, and the mixture of gas and air is ignited. The upward progress of the valve shuts off the flame at *f*, and the burning gases being brought opposite the main port *i* rush into the cylinder, explode, and drive up the piston.

The movement of the two eccentrics O and B is given by the auxiliary shaft M, on which is fixed a ratchet wheel, W. The eccentrics are set to each other at an angle of 90°, and run loose on the shaft, except at certain times. Eccentric O carries the rod working the slide valve S, B has a bell crank, *r*, working on a pivot, and a lever, N. Another lever, L, has a projection, *u*, which, during the greater part of the stroke, presses against *r* and pushes it up, so that it does not catch in the ratchet wheel W of the shaft M. During the down-stroke of the piston a projection, *s*, upon the rack C, strikes the lever L and holds it down, *r* is released and catching into the ratchet wheel on the shaft M causes the two eccentrics to be carried round with it. The slide valve has been stationary during this time, with the exhaust port open to the cylinder. The flap on the slide cover which usually closes it has been lifted by the pressure of the gases, and they are discharged during the down stroke. Meanwhile the piston having reached the bottom of the stroke comes to a stand, because the rack is no longer

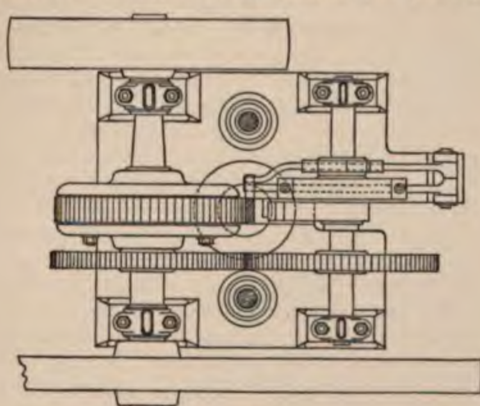

Fig. 9*a*.—Otto and Langen Engine—Plan.

geared to the wheel T. The lever N on the other eccentric B, after revolving with the shaft M, is brought round, and catching under the projection *s* on the rack, lifts it and the piston. The slide valve raised by eccentric O admits and ignites a fresh charge. The up stroke releases the lever L from *s*, the projection *u* pushing against *r* once more disengages it from the shaft M, and the two eccentrics, being no longer connected to [illegible] are brought to a stand. Fig. 9[illegible]ws a plan of the engine.

This description will explain the method of ignition adopted in the Otto and Langen engine. The gases being ignited at low pressure, the ignition by flame, as in all non-compressing engines, worked satisfactorily. The speed was regulated by a ball governor, not shown in the drawing. If the speed of the engine exceeded the proper limits, the governor, by means of a pawl and ratchet, disconnected the levers working the slide valve and piston, and no charge was admitted until the speed was reduced. Thus the number of explosion strokes, instead of the strength of the charge, was diminished. This method worked more economically than direct action of the governor upon the gas admission. It was found that to reduce the proportion of gas impoverished the mixture, the explosion sometimes missed fire, and a certain quantity of unburnt gas passed through the cylinder. A third method of checking the speed was to connect the governor with the opening for the exhaust. By reducing its section, the counter pressure of the gases in the cylinder checked the down stroke of the piston, and therefore diminished the number of strokes per minute.

As the engine was single-acting, working open to the atmosphere, the heat generated was not so great as in the earlier motors. The number of strokes per minute being relatively small, the cylinder was kept comparatively cool. It was not difficult to start the engine, a few turns of the flywheel being sufficient to draw in the charge, and cause it to ignite.

A peculiarity of the Otto and Langen engine is that the number of piston strokes and revolutions of the crank are independent of each other. In an experiment on an engine of this type by Meidinger, the number of revolutions of the crank shaft varied from 40 to 106, and the strokes per minute from 20 to 43. At full power Mr. Clerk reckons the normal number of piston strokes at 30, and of revolutions at 90 per minute.

Another curious feature in this engine is that the action of the walls, which has so injurious an effect in most engines, by carrying off the heat, is here of positive use. During the up stroke, the walls, by rapidly cooling the expanding gases, assist in forming the vacuum, while in the down stroke they carry off the heat, and retard the increase of pressure below the piston.

A number of experiments have been made upon the Otto and Langen engine. Of these the best known is Tresca's trial at the Paris Exhibition, 1867, on a half H.P. engine, lasting half an hour. The number of revolutions per minute was 81; the consumption of Paris gas, not including that used for the burner, was 44 cubic feet per I.H.P. per hour. Tresca estimates that only about 17 per cent. of the total heat was carried off in the cooling water. Another series of experiments, extending over several weeks, was made in 1868 by Meidinger on an engine of the same size. It ran at 75 revolutions per minute, a speed

which Meidinger found to give the best results. The gas consumption per H.P. per hour varied from 49 to 29 cubic feet; the temperature of the exhaust gases was found to decrease with the number of piston strokes per minute. In these trials an experiment was made, by allowing the governor to act sometimes upon the gas admission, sometimes upon the exhaust valve. In both cases the amount of work performed, and the number of revolutions was the same; but when the gas supply was cut off by the governor, the piston made twice as many and much shorter strokes, and the gas consumption was two-sevenths more. Meidinger also utilised these experiments to test the value of ignition at the dead point, and found that it not only prevented shock to the engine, and increased the number of expansions, but also augmented the speed. In an atmospheric engine this increase of speed was valuable, because it principally affected

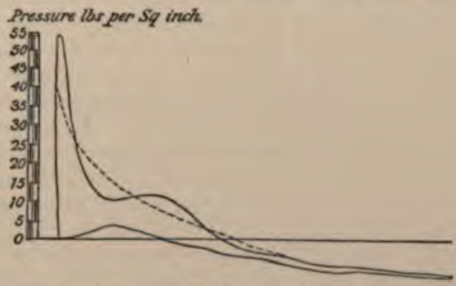


Fig. 10.—Otto and Langen Engine—Indicator Diagram (Clerk).

the speed of the up stroke, and hence gave a more rapid expansion. Mr. D. Clerk also made experiments upon a 2 H.P. Otto and Langen engine, the diagram of which is given in Fig. 10. The consumption of Oldham gas was at the rate of 36 cubic feet per brake H.P., and 24·6 cubic feet per I.H.P. per hour. There were 28 ignitions per minute.

The great defect of the Otto and Langen engine was its ı
and unsteady action, due to the rack and wheel, and tl
sive vibration and recoil. Several efforts were m
course of the next few years to improve upon it,
working principle remained the same.

**Gilles.**—In 1874 an engine was brought out a
Gilles, the chief novelty of which was the intr
pistons, to avoid the noise and recoil of the
motor. The pistons worked vertically one al
the same cylinder, closed at the top, and
to the atmosphere; the lower was the m
the free piston. At starting, the two pis
the middle of the cylinder. By the ene

motor piston being at its upper dead point was driven down, uncovered the port for admission of gas and air at the side, and the charge entered between the two pistons. The free piston was also forced down by air admitted through a valve at the top of the cylinder, until it was checked. The slide valve, through which the charge had entered, was next raised by a cam worked from the main shaft, cut off the admission, and brought the mixture opposite an external firing flame. Explosion followed, and the force drove up the free piston to its full height, the air above it escaping through holes in the cylinder cover. Meanwhile the lower or working piston was forced down through its lowest point, and driven up by the pressure of the atmosphere into the vacuum formed between the two pistons by the cooling of the gases. The upper free piston having reached its highest position, it was arrested, and not allowed to descend, till a second cam on the main shaft moved a lever, and set it free. The products of combustion between the pistons were driven out through a discharge port in the centre of the cylinder.

The Gilles engine was constructed by the firm of Humboldt & Cie., at Kalk, near Cologne, and in England by Messrs. Simon, of Nottingham, who exhibited it at the Paris Exhibition in 1878. The catch arrangement for arresting the upper piston was always a weak point, but before improvements for remedying this and other defects had been introduced, the engine was superseded by the Otto. Two drawings of it will be found in Schöttler.

An extremely useful little engine was introduced by Alexis de Bisschop, and also exhibited at Paris in 1878. Patents dated 1870, 1872, 1874. It resembles an atmospheric engine in principle, but the piston is not free; this engine will be found described in the modern part of this work.

**Hallewell.** — In England a patent for a kind of vertical double-acting atmospheric engine was taken out by Hallewell in August, 1875. Like Gilles, Hallewell aimed at overcoming the defects of the Otto and Langen engine, and this he proposed to do by the use of two cylinders, one single- and the other double-acting. A lever raised the piston of the first single-acting cylinder to admit a charge; explosion followed, and the piston was driven freely up to the top of the cylinder, where a discharge valve opened. It then descended in the vacuum formed below it by the cooling of the gases, and communication was opened between the vacuum and the valve-box of the second double-acting cylinder. In this cylinder air was admitted alternately on either face of the piston, through a rotating slide valve, and with the help of the vacuum in the first cylinder, the piston was driven to and fro by atmospheric pressure. The idea was ingenious but complicated, and the engine had little success.

MM. Otto and Langen had by this time formed their business into a company at Deutz, near Cologne, and the firm was

henceforth known as the "Deutzer Gas-Motoren Fabrik." They had been working incessantly to improve their engine, but after introducing several modifications, they finally abandoned altogether the idea of a free piston. At the Paris Exhibition of 1878 they brought out the celebrated Otto engine, described in Chapter vii., which rapidly superseded all others, and created a revolution in the construction of gas engines. At the same Exhibition two other engines made their appearance which, although neither of them permanently successful, presented several novel and interesting features.

**Brayton.**—This American gas engine had already been introduced by Brayton at Philadelphia in 1873. Owing to the peculiar method of igniting the gases, difficulties were soon experienced, which induced the inventor to substitute petroleum for gas. A full description of his later engine will be found in Part II., Petroleum Motors. In 1878 Messrs. Simon, of Nottingham, obtained Brayton's gas engine patent, and brought out the motor in England. As in the Otto, the charge was compressed, but otherwise this engine differed from all earlier types, and illustrated the principle of ignition at constant pressure, instead of at constant volume. After compression in a separate pump, the gas and air were delivered into the motor cylinder, but they were not admitted cold and then ignited and exploded, according to the usual cycle of operations. A small flame in direct communication with the cylinder was kept constantly alight, and kindled the gases as they passed it. Thus they were gradually ignited, and entering as flame, drove the piston forward, not by the pressure of explosion, but of combustion. The heat was imparted to the gas at constant pressure—that is, the piston moved as soon as the flames began to enter the cylinder, but there was no sudden explosion. A wire gauze was fixed behind the light, to prevent the flame from striking back into the compression cylinder. This method of ignition worked well as long as the wire gauze remained intact, but it was liable to burn into holes, and if the gases found their way back through any aperture, an explosion followed, and the light was extinguished. On this account Brayton abandoned the use of gas in his engine, and substituted petroleum vapour.

**Simon.**—To this gas engine Messrs. Simon added a small boiler above the cylinder, the water in which was evaporated by the heat from the exhaust gases. The engine was vertical and single-acting. The steam injected into the motor cylinder increased the expansive force of the gases, and helped to lubricate the piston. This idea was not a novelty. It had been tried by Hugon, but neither his engine nor the Simon was practically improved by it. The increased bulk added to the cost of construction, and the steam was found to have an injurious effect, and to cool the contents of the cylinder too much. On

this point Professor Schöttler pertinently asks—"Whether it can be considered an advantage, since the gas engine is expressly designed to avoid the defects and dangers of a steam boiler, to add the latter to it? For small motors at least, the question must decidedly be answered in the negative." Although the theoretical principle of the Simon engine was excellent, it did not succeed. It was first shown, like the Brayton, at the Paris Exhibition of 1878.

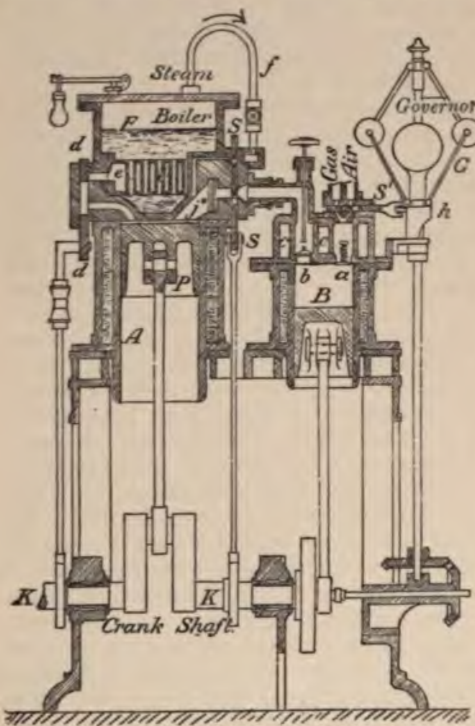


Fig. 11.—Simon Vertical Engine.

Fig. 11 gives a section of the engine; a description will explain the method of working. A is the motor, B the pump cylinder, and K the crank shaft. Gas and air are admitted by the slide valve $S_1$ at the top of the pump cylinder, and drawn in through the valve *a* at the down stroke of the piston; the up stroke compresses and drives them through another valve *b* into the receiver *c*. From here they pass into the motor cylinder A, through the slide valve S; *j* is a gas jet burning continually in front of a wire gauze, at which the gases are ignited in their passage, and by their expansion drive down the piston P. The exhaust is worked by the slide valve *d*, driven from the main shaft. The products of combustion are led through the coiled tubes *e* in the small boiler F, before discharging into the atmosphere. As soon as some of the water in the boiler is evaporated by the heat of the exhaust gases, the steam passes through the pipe *f* and slide valve S into the motor cylinder. A small cam, *h*, on the governor G acts upon the slide valve $S_1$ for admitting the gas and air, and

cuts off the admission entirely, as soon as the speed of the engine becomes too great; this is shown in Fig. 11.

Several experiments have been made upon the Brayton and Simon engines. In 1873 Professor Thurston tested a Brayton engine in America, of 5 nominal H.P., and found that the maximum pressure in the cylinder was about 75 lbs. per square inch at the beginning of the stroke, decreasing to 66 lbs. at the cut off. The H.P. indicated 8·62, brake power 3·98, and consumption of gas 32 cubic feet per I.H.P. per hour. According to Mr. Clerk the power used for driving the pump, which causes the actual horse-power to be less than half the indicated, ought not to be included in estimating the consumption of gas. Deducting this, he calculates the expenditure at 55·2 cubic feet per H.P. per hour. Another experiment made by Mr. M'Mutrie, of Boston, showed a maximum pressure in the cylinder of 68 lbs. per square inch, the piston speed was 180 feet per minute, and the total power developed 9 H.P., the friction and other resistance amounting to nearly 5 H.P. Fig. 12 shows the diagram of this trial. In an experiment made upon a Simon engine of 7·7 I.H.P., 2 H.P. were required for the pump, and the total gas consumption was 50 cubic feet per brake H.P. per hour. The diagram of a Simon engine at Fig. 13 was taken by Dr. Slaby.

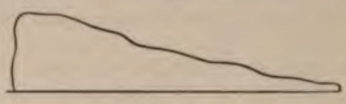

Fig. 12.—Brayton Gas Engine—Indicator Diagram.

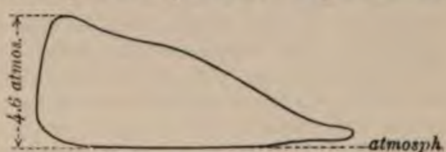


Fig. 13.—Simon Engine—Indicator Diagram.

The engine was brought out in Germany by the firm of Otto Hennig & Cie. of Berlin, by whom several improvements were introduced, patented by Hambruch. As in the original engine the flame was sometimes blown out by the pressure of the gas, it was protected by a small cap and cover, and the burner made in the shape of a cock, with a handle to lift it out and relight it, if extinguished. In the larger engines, the ignition flame was fed from a separate small gas pump. Another improvement was to replace the exhaust and admission slide valves of the Simon engine by lift valves. The admission valve was opened by a tappet working in a socket on the main crank shaft. If the speed was too great, the governor at the end of the crank shaft drew the socket to one side, and the tappet missed it partially or altogether. Air entered the admission valve from below, gas was admitted through small holes in the seat of the valve, as in the Clerk engine, and a thorough mixing of the two was thus

attained. There was also an ingenious arrangement for equalising the pressure in the pump and motor cylinders. The admission valve, being very heavy, did not lift until the pump piston was halfway through the up stroke. A small piston above it worked in a pipe connected to the motor cylinder, and a hole in the motor piston fitted over the opening of the pipe during the down stroke. As soon as communication was established, and the pressure in the two cylinders equalised, the admission valve fell back upon its seat, and remained closed until the next up stroke.

**Ravel Rotatory Engine.**—Another interesting engine, two varieties of which were shown at the Paris Exhibition of 1878, was the French "Moteur Ravel." The first type was double-acting and rotatory, and was called by the inventor "an engine with variable centre of gravity." The cylinder turned upon a transverse axis, and had two heavy pistons joined together by a bar of iron, without piston-rod or connecting-rod. Gas and air were first admitted and compressed in two small pumps worked from the crank shaft, and the charge introduced alternately at either end—that is, at the top and bottom of the motor cylinder, as long as it retained a vertical position. By the explosion at the bottom of the cylinder both pistons were forced up together to the top, to be driven down again by the explosion of the compressed charge from the other pump cylinder. The motor pistons being very heavy, their motion altered the centre of gravity, and caused the cylinder, while oscillating, to turn round on its axis. The crank shaft in the centre was made to rotate by the movement of the pistons and cylinder, the piston speed being independent of the number of revolutions. The extreme delicacy of adjustment required in this engine caused it to be superseded by others; the consumption of gas was said to be about 35 cubic feet per H.P. per hour. Two drawings of the Ravel rotatory motor will be found in *Schöttler*, p. 36.

**Ravel Oscillating Engine.**—Another vertical oscillating single-acting type of the same engine was brought out by M. Ravel, and more favourably received in France. In this motor the piston-rod was directly connected to the crank shaft. The vertical cylinder oscillated on a centre at its lowest part. The force of the explosion drove up the piston and crank shaft, causing the cylinder to oscillate and the crank shaft to rotate. The piston descended by the impetus of the flywheel, and the shaft having completed its revolution, the cylinder returned to its original position. The action was very similar to that of an oscillating steam engine. Gas and air were admitted at atmospheric pressure through a slide valve, worked by a cam on the main shaft, oscillating with the cylinder. Ignition was effected by an external flame in the ordinary manner. There was no

special exhaust valve, but the exhaust port was uncovered periodically by the oscillation of the cylinder. Gas entered through a pipe in the slide valve, moving to and fro in the valve cover, which opened by degrees to admit an increasingly rich charge; thus the mixture finally admitted nearest the flame contained most gas and was more easily ignited. The governor acted by throttling the supply of gas. This engine was said, like the last, to consume 35 cubic feet of gas per H.P. per hour, but it is doubtful whether so low a consumption could be obtained in a gas engine working without compression.

**Foulis.**—The horizontal engine patented by Foulis of Glasgow in 1878, an improved type of which was brought out in 1881, resembled the Simon in principle, and contained a motor cylinder and pump. The object aimed at by the inventor was to cause combustion to take place in the motor cylinder, at about the same pressure as that in the pump. This was obtained by adjusting the angle of the crank-pin working the pump, and proportioning the dimensions of the latter to those of the motor cylinder. In theory the engine was excellent. The hot gases, after being compressed in a pump, were forced through layers of wire gauze and an annular orifice into the combustion chamber, lined with non-conducting material, and kept at a red heat which sufficed to ignite the charge. From here they passed at constant pressure and in a state of flame into the motor cylinder. Admission was cut off at one-third of the stroke. Before being allowed to escape, the gases of combustion were made to circulate round tubes of fire-clay behind the combustion chamber, which were intended to act as a regenerator. The fresh charge passed through them immediately after, and some of the heat of the exhaust gases was thus utilised, but these and other details presented so many difficulties that the construction of the engine was afterwards given up. To raise the temperature of the incoming charge in a gas engine by means of the exhaust heat is an important problem, which inventors have hitherto been unable to solve successfully.

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## CHAPTER VI.

### HISTORY OF THE GAS ENGINE—(*Continued*).

CONTENTS.—Engines—Clerk—Beck—Wittig and Hees—Seraine—Sturgeon—Martini—Tangye—Victoria—Economic—Bénier and Lamart—Forest—Ewins and Newman—François—Warchalowski—Noël—Durand—Mire—Baldwin.

IN a history of the development of the gas engine it is important to study, not only modern working motors, but those engines

which, although no longer made, are good in design and principle, and, therefore, deserve attention. During the last twenty years many motors have been brought out, excellent in theory and often in workmanship, which have not permanently succeeded only because they were found to infringe previous patents, or were superseded by more practical types. As none of these engines date earlier than 1878, they will not be presented in historical sequence, but, as far as possible, in the order of their importance. From henceforth it will no longer be necessary to distinguish between single-acting and double-acting engines. The double-acting type of motor, in which the charge was introduced alternately at either end of the closed cylinder, was abandoned after the failure of the Hugon, for reasons already given. Since that period no engines of this kind have, to the author's knowledge, been constructed, with the exception of the modified Griffin six-cycle motor. All others are single-acting, or admit the charge at one end only of the cylinder.

With the advent of the Otto gas engine, a new era began. Until the appearance of this motor in 1876, not one of the many engines produced had utilised the cycle of operations indicated, many years before, as the best and most economical by Beau de Rochas. Neither invention nor practical application was wanting, and as none had proved a real success, we may at least assume that their failure was due partly to the neglect of this cycle. It is Otto's special merit that he was skilful enough to put the principles of the French *savant* into working operation, and the success of his engine proved their value. It had, however, defects, which in a few years began to be generally recognised. As in all other gas engines, expansion was not complete, and the gases were discharged at a relatively high temperature and pressure. The engine had also only one explosion and one motor stroke in four—that is, three strokes out of every four of which the cycle consisted, were spent in negative work, and only one in positive work.

**Clerk.**—It was to remedy the second of these defects that Mr. Dugald Clerk applied himself, in the important engine he produced and first exhibited in 1880. This motor, which is certainly one of the best brought out in England, was made by Messrs. Thomson, Sterne & Co., of Glasgow. Its distinguishing feature was that an explosion at every revolution was obtained. Of the four operations of the cycle, Clerk proposed to transfer the first only, admission, to an auxiliary cylinder, which he called the displacer. The gas and air being drawn into the displacer were slightly compressed, and delivered into the working cylinder. Here they drove out before them the products of combustion. The motor piston in returning compressed this charge into a chamber at the further end of the cylinder. It was then fired and drove the piston forward, the displacer piston

taking in a fresh charge of gas and air. The exhaust ports were in the front part of the cylinder, and the piston as it moved out uncovered them, and acted as an exhaust valve. The discharge of the exhaust gases constitutes another fundamental difference between the Otto and the Clerk engines. Otto considered that the presence of a certain quantity of unburnt gases, by retarding the progress of combustion, contributed to the efficiency of his engine. Clerk held that this residuum of unconsumed gas was highly injurious to the fresh charge, which it diluted and rendered more difficult to ignite. He was of opinion that if the motor cylinder were previously cleansed, as

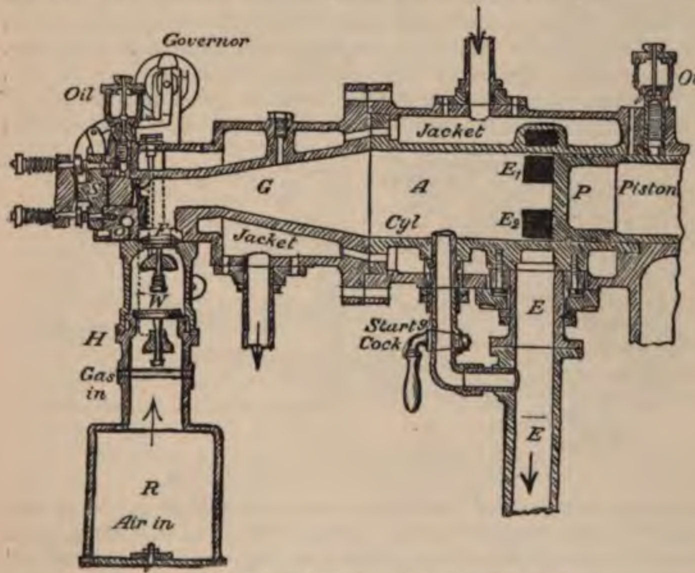


Fig. 14.—Clerk Engine—Sectional Elevation.

far as possible, of the products of combustion, a weaker mixture might be used for the charge, and more perfect ignition and greater economy obtained.

Figs. 14 and 15 give a sectional elevation and plan of the Clerk engine. A is the motor cylinder with piston P, B is the displacer cylinder with piston D, which is set on the crank at an angle of 90° in advance of the motor piston, G is the conical compression space at the back of cylinder A. There are two automatic lift valves, shown at Fig 14, H, from which the gas and air pass through the pipe W (Fig. 15) into the displacer cylinder, and F, which is raised to admit the charge under slight pressure into cylinder A. Both the valves are provided with

"quieting pistons," to prevent any noise or shock. The ignition slide valve S has a flame *o* which is continually relit from the permanent Bunsen burner at *b*. Near the front of the motor cylinder are the two exhaust ports $E_1$ and $E_2$, uncovered by the piston P when it reaches the end of its stroke, and from whence the gases of combustion pass into the discharge pipe E.

The action of the engine is as follows:—The piston D of the displacer moves out, and draws in a charge of gas and air through H. The seat of this valve is pierced with holes to admit gas from the supply pipe, the forward movement of the displacer piston lifts the valve, the air enters from chamber R below, and mixes thoroughly with the gas penetrating through the holes. The number and size of the holes, in proportion to the lifting area of the valve, regulate the supply of gas, and, therefore, the richness of the mixture. The air valve H falls back on its seat by its own weight, but the gas supply is cut off before the piston D has quite reached the end of its stroke. The

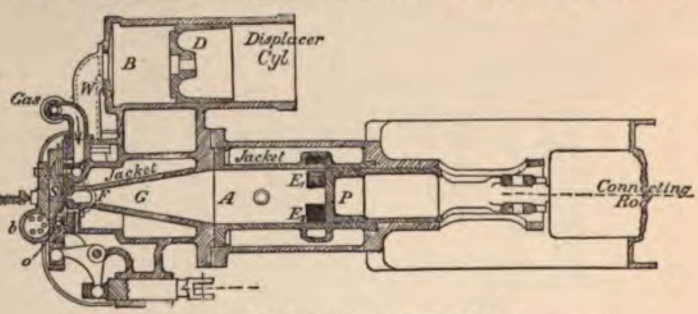


Fig. 15.—Clerk Engine—Sectional Plan.

last part, therefore, of the charge in the displacer cylinder, first expelled as the piston begins to return, is pure air. Meanwhile the out stroke of the motor piston has begun, at an angle of 90° behind that of the displacer, and near the end of the stroke the exhaust ports $E_1$ and $E_2$ are uncovered. The pressure inside the motor cylinder is immediately reduced to that of the atmosphere. The displacer piston has already nearly completed its return stroke, and the slight pressure exerted on the charge is sufficient to lift the automatic valve F, and to admit the gas and air into the conical chamber G, at the end of the motor cylinder. As the motor piston passes over the exhaust ports, the fresh charge entering [illegible] displacer, and immediately expanded by the [illegible] inder, drives out the products of com- [illegible] lerk admits that a small part of the [illegible] them, but as, owing to the arrange- [illegible] , this is mostly pure air, the cylinder [illegible] very little actual waste of unburnt

gas. The motor piston in returning first covers the exhaust ports, the valve F is instantly closed by a spring, and admission from the pump cylinder cut off. The mixture is then compressed into the chamber G, while the displacer piston begins the out stroke, and takes in a fresh charge.

Ignition follows by a flame in the slide valve S. The method adopted, shown in Fig. 15, but more clearly in Fig. 16, differs from that used in engines having only one motor stroke in four, because an ignition is required at every stroke. With the high pressure of the gases, and the great number of explosions, sometimes nearly 300 per minute, the slide would soon become red-hot, unless special precautions were taken to prevent it. The small combustion chamber or cavity 1, Fig. 16, in slide valve S, has two openings. On one side it communicates with the Bunsen burner $b$ through the port 2, on the other by port 3 with the outer air, or with the explosion port of the cylinder, according to the position of the slide. A small portion of the compressed mixture is admitted from the explosion port 5, through an opening 4, into a grooved hollow in the slide valve, and is carried round to the cavity or chamber 1, which it enters behind a grating 7, intended to prevent the flame from striking back into the hollow. At 8 is shown the pin in the slide regulating the supply of gas to the grating. At the moment when port 2 of the cavity is open to the Bunsen jet burning against the face of the valve, port 3 communicates through 6 with the outer air. The gases ignite gradually as they enter the cavity through the grating, the products of combustion discharging into the atmosphere, and the gases being fed with air through port 6. As the slide moves up, carrying the burning mixture, port 2 is closed and the flame cut off, and port 3 is brought opposite the cylinder explosion port. The current feeding the flame in the cavity is so regulated, that the pressure of the ignited gases is less than that in the motor cylinder; hence the charge is easily fired. Explosion follows at the inner dead point, the piston is driven forward, the displacer takes in a fresh charge, and the cycle is repeated.

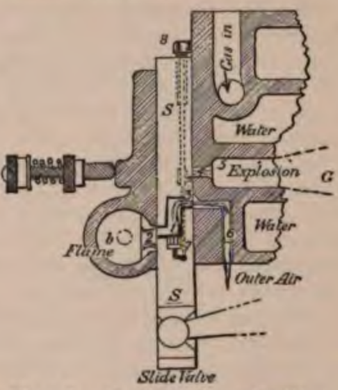

Fig. 16.—Clerk Engine—Ignition Valve.

Great care has been taken in this engine to proportion the volume of the two cylinders, to prevent the escape of any considerable part of the incoming charge with the exhaust gases. The

volume of cylinder B is almost exactly equal to that of cylinder A, deducting the compression space G, and the exhaust ports covered by the piston. But as the gases expand in consequence of the slight pressure in cylinder B, and the heat of the walls in cylinder A, their volume is increased by one-third. The mixture originally admitted is in the proportion of 1 part of gas to 8 of air. To avoid the discharge of any of the fresh gases, a small part of the products of combustion remains in the cylinder; this mixes with the fresh charge, and is estimated by Mr. Clerk as one-tenth of the total volume. The composition of the actual charge will, therefore, be 1 of gas to 10 of air and products.

**Clerk Governor.**—The governor in the Clerk engine is simple. Between the upper and lower lifting valves for admitting the charge to the motor and displacer cylinders is a gridiron slide. While the engine is working under normal conditions, this is kept open during the charging stroke by a spring and lever, worked from the slide valve S; but if the speed becomes too great, the balls of the governor moving out raise a lever, which catches into the lever moving the gridiron valve, and lifts it. The valve is drawn forward and closed, and the admission of gas and air wholly cut off. The two pistons continue working, but compress and discharge only the products of combustion, until the speed is reduced, and the levers lowered. This method of regulating by a gridiron slide was the invention of Mr. Garrett, of Messrs. Sterne's Works. Above each cylinder is a small oil reservoir, with an adjustable screw admitting so many drops per minute.

For starting, a special apparatus was designed by Mr. Clerk in 1883. The pipe through which the gases pass from the displacer to the motor cylinder can be made to communicate with a small reservoir, and a supply of gas and air forced into it, while the engine is running. The reservoir, charged with the mixture compressed to 60 lbs. per square inch, is closed with a stop valve, and can be kept air-tight for weeks. To start the engine, the crank is brought round to the inner dead point, the displacer piston being set at a quarter of its stroke. Communication is then established between the two cylinders and the reservoir, and the burner lit. The compressed air is thus admitted to both cylinders, and drives back the displacer piston to take in a charge, and the motor to uncover the exhaust ports. It is usually sufficient to open the starting valve once or twice, but the reservoir contains enough to start the engine six times.

Tests and experiments on the Clerk engine have been made by the inventor and the makers. The engines varied from 2 H.P. to 12 H.P., and the number of revolutions from 212 to 132. With the 2 H.P. engine the average pressure in the cylinder was [illegible] lbs. per square inch, and the consumption of gas per I.H.P. [illegible] hour 29·8 cubic feet; in the 4 H.P. the average pressure was

63·9 lbs. and the gas consumption 24·19 cubic feet. The 6 H.P. engine (Diagram, Fig 17) gave an average pressure of 53·2 lbs. per square inch, with 24·3 cubic feet of gas consumption; in the 8 H.P. the pressure was 60·3 lbs. and a gas consumption of 20·94 cubic feet, while in the larger 12 H.P. engine, the diagram of

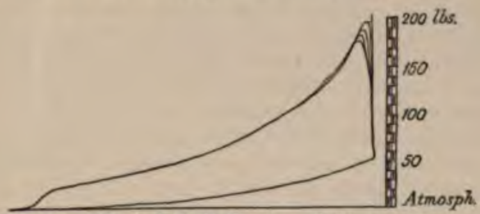


Fig. 17.—Clerk 6 H.P. Engine—Indicator Diagram.

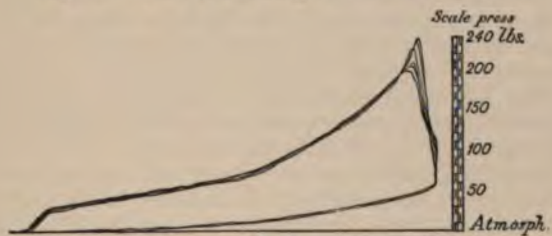


Fig. 18.—Clerk 12 H.P. Indicator Diagram.

which is shown at Fig. 18, the gas consumption was 20·39 cubic feet, with an average pressure of 64·8 lbs. It will be observed that the consumption of gas diminishes in proportion as the size, power, and pressure increase. The Glasgow gas used was very rich, and of high heating value.

The foregoing sketch of the Clerk engine shows that, though good in theory and practice, it did not completely overcome the defect of the Otto and many other gas engines, the want of sufficient expansion. As the exhaust ports opened when the motor piston had passed through three quarters of its stroke, expansion was necessarily limited. This was a great disadvantage, but the engine was good in other respects, and more economical in working than previous motors, and its withdrawal from the market is to be regretted. Mr. Clerk calculates the actual efficiency indicated by the diagrams as 16 per cent. of the total heat received, a very creditable result.

**Beck Six-Cycle Type.**—The Beck engine is the first example of a new cycle of operations. It belongs neither to the original double-acting two-cycle type, giving an explosion every revolution, nor to the four-cycle type of Beau de Rochas, but is known as a six-cycle engine. In other words, there is an explosion every sixth stroke, or the piston makes three forward and three

return strokes for three revolutions of the crank. The object of thus lengthening the ordinary sequence of operations is to drive out more completely the products of combustion by introducing, between every explosion and motor stroke, one stroke, forward and return, during which a charge of pure air is drawn in and expelled. This is called a "scavenger charge," and was first proposed by Mr. D. Clerk, who to a certain extent adopted the principle in his engine, though he did not sacrifice two strokes. Engineers are even now divided in opinion respecting the best method of disposing of the products of combustion. By Otto they are purposely retained, in order to diminish the force of the explosion, and he and others have thought that there is an advantage in diluting the incoming charge with the burnt gases. At the same time it must not be forgotten, that these gases help to heat the fresh charge before explosion. Other engineers are so strongly convinced of the injurious effect of leaving behind any portion of the products of combustion that, in order thoroughly to get rid of them, they sacrifice a complete stroke. The advantage they claim in return for this diminution of power is that, the cylinder being thoroughly cleansed, the incoming charge is so pure that a much weaker mixture may be employed, and more rapid and certain explosion obtained, than when the products of combustion are allowed to remain. With only one explosion every six strokes, there is, of course, great difficulty in regulating the speed of the engine, and the cooling action on the cylinder walls of the charge of fresh air is also considerable. For these reasons the six-cycle type has found little favour, and is seldom seen out of England. It is best adapted to double-acting engines, adjusted to give an explosion every three strokes, first at one, then at the other end of the piston. With this modification it has survived to the present time; the Griffin engine is a good example.

The Beck engine was always of the original six-cycle type, single-acting, and was never constructed to give more than one explosion per six strokes. The working cycle of operations is explained by the following table:—

| Revs. of Crank. | | | | |
|---|---|---|---|---|
| 1 | First stroke, forward. | Admission of charge. | Negative stroke absorbing power. | Three revolutions per explosion (one cylinder). |
| | Second stroke, return. | Compression of charge. | | |
| 2 | Third stroke, forward. | Ignition, explosion, expansion. | Positive (*motor*) stroke giving power. | |
| | Fourth stroke, return. | Discharge and exhaust. | Negative stroke absorbing power. | |
| 3 | Fifth stroke, forward. | Admission of pure air. | | |
| | Sixth stroke, return. | Discharge of air to atmosphere. | | |

Except with regard to the scavenger charge of pure air, the engine resembled the Otto in many respects. Admission and ignition were effected by a slide valve not connected direct to the excentric from the motor shaft. The slide valve was adjusted to make one-third as many revolutions as the crank shaft. The compression space was separated from the water jacket by a cylindrical layer of non-conducting materials, and the mixture was thus ignited in a chamber kept continually at a high temperature. By introducing the scavenger charge of pure air, and by adjusting the admission valves, the richest mixture, namely that containing most gas, entered the cylinder first, and the poorest mixture was retained round the ignition port. By these means it was intended to diminish the shock to the engine, and to obtain progressive explosion. An electrical governor was employed, and the intensity of the current was made to vary with the speed of the engine. According to the variation in the speed, the admission of gas was either throttled or wholly cut off. The governor was adjusted so that, by moving a weight on a lever, the speed could be diminished by 100 revolutions; thus the engine, when running empty for a short time, could be driven slower, instead of stopping altogether. As a six-cycle engine is naturally more difficult to start than a two- or four-cycle motor, this is a convenient arrangement.

**Beck Trials.**—A series of very careful experiments upon a 4 H.P. nominal Beck engine were made in London by Professor Kennedy, F.R.S., in February, 1888, and published. The indicated and brake power, speed, consumption of gas, and jacket water were all carefully observed in six successive trials. Two of these were made at full speed, at 206 and 212 revolutions per minute, and practically at full power, the next two at a mean speed of 166 revolutions, the fifth at 180 revolutions, with the maximum load for that speed, and the sixth with the engine running empty. The highest power developed was 8 I.H.P., with 6·3 B.H.P. The maximum pressure during the working stroke was 74·6 lbs., and at the highest

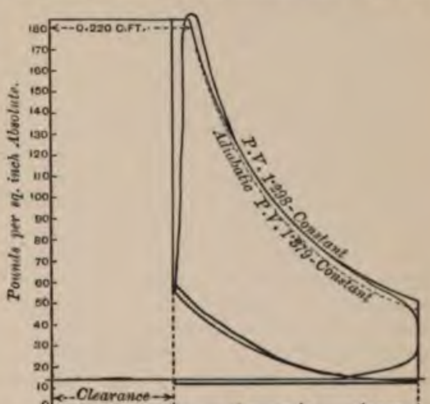

Fig. 19.—Beck Engine—Indicator Diagram.

speed there were 70·68 explosions per minute. The B.H.P. varied from 6·31, with 206·5 revolutions, to 4·84, with 169 revolutions. Taking the mean of the first four experiments, the average consumption of gas was 21·42 cubic feet per I.H.P., and 26·79 cubic feet per B.H.P. per hour. The gas used was of excellent quality, although its calorific value was not very high —viz., 611·4 thermal units per cubic foot. The proportions of the mixture were 11·5 of air to 1 of gas. One of the diagrams of the trial, No. 1, is given at Fig. 19.

**Wittig & Hees.**—A vertical engine, by this firm, was made for some time in Germany, and tested by Professor Schöttler in 1881. As in the Clerk engine, there is a pump and a motor cylinder, and both are enclosed in a hollow cast-iron casing filled with water, which forms the cooling jacket. The shaft is above it, and both cranks connected to the two plunger pistons are set at the same angle. This is a two-cycle engine of the usual type where compression is used. The pump piston draws in the gas and air during the up stroke, while the motor piston is driven up at the same time by the force of the explosion and expansion of the charge beneath it. In the down stroke the pump piston compresses the gases, and before the end of the stroke the pressure opens a valve in a large pipe connecting the two cylinders, and thus establishes communication between them. Meanwhile the motor piston, in descending, drives out the gases of combustion at the beginning of the down stroke through the exhaust valve, which is on the opposite side of the motor cylinder to the pump, and is worked by a cam on the main shaft. When the piston has passed through three-fifths of its stroke the exhaust closes, and the products left in the cylinder are compressed, while the pump delivers the fresh charge through the return valve. During the latter part of the down stroke, therefore, both pistons are compressing, and the incoming gas and air are thoroughly mixed with the exhaust gases. The force of the explosion then closes the return valve, and shuts off communication between the two cylinders. The ball governor acts upon the gas admission valve. The latter is usually worked

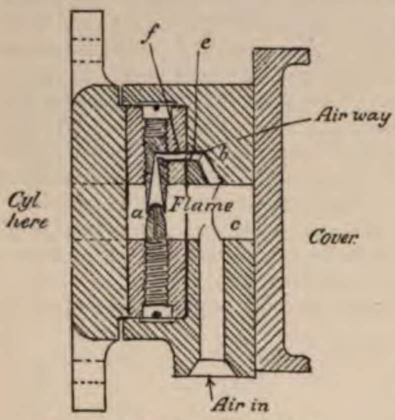


Fig. 20.—Wittig & Hees Engine—Ignition Valve (Sectional Plan).

by a cam from the main shaft, which presses down the upper movable part of the valve-rod, and opens the valve. If the speed is too great, and the balls of the governor rise, a lever pushes aside the top of the valve-rod and, the cam being missed, no gas is admitted.

Ignition is effected at the lower dead point by a novel method, seen at Fig. 20, also employed in the Sombart engine. An external flame, not shown in the drawing, burns in the slide cover. When the valve is in its lowest position, the cavity *a* in the slide valve communicates with the flame and, through the small channel *b*, with the compressed charge from the valve chest *c*, while air is drawn in through an opening near the bottom of the slide valve. The mixture in cavity *a* being ignited, the valve rises, cuts off communication with the outer flame and the air, and an explosion follows as soon as *a* communicates at *c* with the fresh charge in the motor cylinder. Thus far the ignition is almost the same as in the Clerk engine. In order that the flame may be at the same pressure as the mixture in the cylinder, and the light not blown out during the upward movement of the slide by the rush of the compressed charge, there is a continuous flow of gas through *b* and the hollows *e* and *f* into the cavity. In the slide valve are two small pins opposite each other; the one is hollow, and filled with the burning gas, forming a continuation of the grove *f*. The other is conical in shape, and fits like an extinguisher over the flame, diminishing or increasing the flow of gas, according to the position of the slide.

In a 2 H.P. (nominal) engine, tested by MM. Schöttler and Brauer, the number of revolutions were 105·5, and the consumption of gas per I.H.P. per hour 39 cubic feet. In another 4 H.P. engine, tested by them at the Altona Exhibition in 1881, the number of revolutions per minute was 103, and the quantity of gas consumed was 43 cubic feet per I.H.P. per hour. Details of this experiment will be found in the table given in the Appendix.

In all the engines hitherto described, expansion of the charge during one forward stroke, or part of a stroke, of the piston was only in the same ratio as the other operations. Of the two great improvements on the original type, compression and expansion, the first, compression of the gas and air after admission, already formed a part of almost every cycle, but expansion was still imperfect. Even now, inventors have not succeeded in increasing it so as to utilise to the utmost the high pressures and temperatures obtained. Various schemes have been proposed, and various methods suggested to remedy this defect. The three following engines exhibit different attempts to obtain greater expansion, though none of them have succeeded in overcoming the initial difficulties, and in realising a good working cycle.

**Seraine.**—The type adopted in the Seraine, a vertical engine patented in France in 1884, was not in itself new, except as applied to gas engines. One cylinder and one piston only are used, serving the double purpose of pump and motor; the crank shaft is at the top, above the cylinder. Gas and air are admitted in the upper part, and compressed by the up stroke of the piston into a receiver below. To make this compression space smaller than the explosion space at the bottom of the cylinder, where the gases expand—that is, to increase expansion in proportion to compression, the piston-rod is of larger diameter and the stroke is lengthened, thus the area of the upper face is smaller than that of the lower. This type of piston, having a top area less than the bottom, is called a differential piston. The working of the engine is as follows:—The down stroke draws in air and gas at the top of the piston, which are compressed by the next up stroke and driven into a receiver. A slide valve worked from the main shaft now descends, shuts the exhaust and opens a passage for the compressed mixture into the lower part of the cylinder. The valve as it rises cuts off the admission, the charge at high pressure is forced into an explosion chamber in the slide valve, and ignited from a light burning in a hollow. A permanent outside flame rekindles the light when blown out. The exploded charge, striking back into the cylinder, drives up the piston, and expands during the whole motor stroke. The exhaust is not opened till the slide valve begins to descend. The gas consumption of this engine was said to be only 21 cubic feet per I.H.P. per hour. It bears a certain resemblance to a gas engine patented, but never constructed by Sir W. Siemens; the principle of compression by the upper face of the piston will be found in several modern motors. Two drawings of the Seraine engine are given in Schöttler, p. 161.

**Sturgeon.**—Another much more complicated two-cylinder compression engine, the Sturgeon (Fig. 21), was shown at the Exhibition in Manchester in 1887, by Messrs. Wallwork & Co. Here the problem how to obtain greater expansion in proportion to compression was ingeniously dealt with, but at the expense of simplicity of construction. The method was similar to that used in Atkinson's first engine, which certainly resembles the Sturgeon, but the means employed were rather intricate. There are two cylinders and three pistons. The front or charging cylinder B is horizontal, and its piston *p* acts as a pump; the second or motor cylinder A is vertical behind B and has two pistons, P and P′; the four exhaust valves seen at *a* are at either end of cylinder A. The three pistons, shown in the drawing, work through their respective connecting-rods and levers upon the crank shaft; they are all trunk pistons and single-acting. The slide valves S between cylinders B and A are horizontal, in line with the crank shaft, and driven from it. As

the piston $p$ of cylinder B moves out, it draws in the charge of gas and air through the slide valve below; in its return stroke it slightly compresses the mixture into the vertical cylinder A, and the return stroke of the other two pistons taking place at the same moment, the charge is further compressed between them. Explosion follows in cylinder A at the in stroke, and all the pistons are driven outwards and forwards, but as the pump cylinder B is shorter than the other, piston $p$ begins to return while the motor pistons are still moving out. Hence, the charge it has taken in during the out stroke is compressed into the motor cylinder at the moment when the other pistons, near the end of their out stroke, uncover the exhaust ports, and the com-

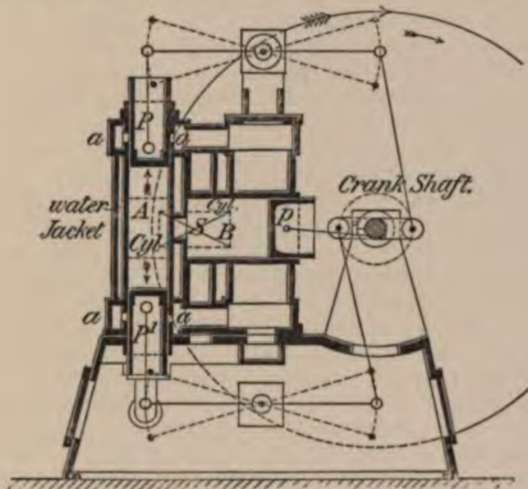


Fig. 21.—Sturgeon Gas Engine—Sectional Elevation.

pressed charge from B helps to drive out the products of combustion. As the motor pistons begin to return the exhaust ports are shut, and all three pistons, moving simultaneously inwards, continue to compress the charge within very narrow limits. The principle of the engine is to admit the charge in the smaller, and expand it in the larger cylinder, and thus to increase the proportion of expansion to admission and compression. The engine attracted attention at the Exhibition by its noiseless working, due to the relatively large expansion space, but the number of working parts was great, and the construction was soon given up.

**Martini.** — A third (French) engine of the same type, the Martini, patented in 1883, was first shown at the Paris Exhibition of 1889. If made, it does not appear to have worked, but

it is interesting as presenting another development of the idea of increased expansion, afterwards practically and successfully treated by Mr. Atkinson. It is a four-cycle engine, in which admission and compression are effected during one revolution with a shorter stroke, and expansion and exhaust during the next with a longer stroke. Like the Otto, therefore, it has only one motor stroke in four. The junction of the connecting-rod and the motor shaft is effected by levers in the shape of an isosceles triangle; the point of contact describes a double curve forming two unequal circles. The larger circle is described by the crank during expansion and exhaust, and the smaller during admission and compression. The ratio, or difference in diameter of the two circles, depends on the position of this point of junction, and the length of stroke can be modified by varying the inclination of the axis of the cylinder to the axis of the motor shaft. The double circle described by the connecting-rod at the point of junction is not symmetrical with the axis of the cylinder, but so deviates that the piston approaches the explosion end of the cylinder more nearly during compression than during exhaust. The automatic ignition is effected in the ordinary way by an external flame. The admission and exhaust valves are worked by levers from the main shaft. Drawings of this curious engine are given in M. Richard's* book. M. Martini, whose works are at Frauenfeld in Switzerland, now constructs four-cycle engines of the ordinary Otto type.

**Tangye.**—A compact and handy horizontal motor, embodying several of the improvements already described, and resembling in certain respects the Clerk and Seraine engines, was constructed formerly by Messrs. Tangye of Birmingham, after Robson's patent. There is one cylinder closed at both ends, and the piston-rod works through a stuffing-box. Explosion takes place at the back end of the cylinder, furthest from the crank, and with the help of an auxiliary chamber, an impulse every revolution is obtained. At the crank end the charge is admitted at atmospheric, and passed on at slightly increased pressure into an auxiliary chamber, from which it is drawn in at the other end of the cylinder, and compressed, ignited, and expanded. The openings for the exhaust are at the crank end. The engine works as follows:—On the crank face of the piston the return stroke admits the mixture of gas and air, and the forward (expansion) stroke compresses it into the auxiliary chamber at a pressure of 5 lbs. above atmosphere. At the end of this out stroke the piston overruns the exhaust ports and reduces the pressure in the cylinder below atmosphere. The slight pressure of the charge in the receiver is sufficient to lift an automatic valve, forming the communication between it and the back part of the motor cylinder. A fresh charge enters and

* *Les Moteurs à Gaz.* Par G. Richard.

drives out the products of combustion. The return stroke compresses this charge at the front end of the piston, ignition at the dead point follows, and the force of the explosion again drives the piston forward. Thus one revolution completes the whole working cycle, and by storing up the pressure in an intermediate receiver, and utilising both faces of the piston, one explosion per revolution is obtained. This is an interesting little engine, but probably uneconomical, since the gases must be discharged at too high a pressure and temperature, and a portion of the fresh charge apparently escapes with them. A drawing is given by Clerk.* The makers have now adopted the usual Otto type, as described in the modern section.

**Victoria.**—The "Victoria" engine, manufactured at Chemnitz in Germany, was shown at the Munich Exhibition in 1888. In this motor the cylinder is placed vertically on a box-shaped base, carrying the bearings for the crank shaft below. The base is divided horizontally into two parts. Through holes in the upper part the outer air to dilute the charge is drawn, and led by a pipe to the admission valves; the exhaust gases are carried into the lower part and there discharged. The piston and cylinder above the crank shaft are very long, and the top of the cylinder forms a guide. Explosion takes place below the piston, driving it up, and the motion is transmitted to the crank shaft through a crosshead and two connecting-rods. The admission and exhaust valves on opposite sides of the cylinder are worked by the same cam on the crank shaft through levers. The gas pipe surrounds the admission valve-rod, and gas and air are admitted simultaneously. The governor acts by interrupting communication between the gas valve and the levers and cam. The gases are ignited by a flame through a hollow tube, on the same principle as in the Koerting engine; this ignition tube is worked from another cam on the crank shaft. All the valves are held on their seats by springs. A drawing is given by Schöttler.

Three small gas motors, none of them exceeding 1 H.P., were brought out abroad about ten years ago, though they do not appear to have found their way into England. In all of them the charge was introduced at atmospheric pressure. It was difficult, without infringing the Otto patent, to produce single cylinder engines using compression. For small powers, therefore, compression and the resulting economy not being of so much importance as simplicity, the easier method of firing the charge without previous compression was preferred. As the temperature in the cylinder was thus reduced, a water jacket, in two of these engines, was dispensed with. The cylinders were ribbed externally to afford a larger cooling surface, and in this and other respects they resembled the Bisschop.

* Clerk, *The Gas Engine*, p. 196.

**Economic.**—The first was a vertical half H.P. engine, called the "Economic" motor, introduced into Europe in 1883 by a Company of the same name in New York. The external surface of the cylinder is ribbed, and the connecting-rod and piston, from which the crank shaft is worked, are attached to a beam. A small crank, driven from the main shaft, works a piston valve, which uncovers the valves admitting gas and air, and the opening into the exhaust. The motor piston draws a charge of gas and air into the cylinder through this valve. It is then ignited and an explosion occurs, as soon as the working piston has passed a platinum disc, maintained at a red heat by an external flame. The governing of the engine is ingenious but complicated. On the opposite side to the cylinder is an air pump worked from the beam. Part of the air thus compressed is used to feed the ignition flame, but if the speed increases, and a larger quantity of air is introduced, it presses down a disc, cutting off the supply of gas. This method was afterwards given up, and the governor allowed to act directly on the gas valve. A drawing of the engine will be found in Witz's work.*

**Bénier and Lamart.**—The Bénier and Lamart was another small vertical non-compression motor, introduced in 1882, which was said to combine simplicity and compactness with good working conditions. The engine stands on a strong cast-iron base, and all the parts are brought as closely together as possible. To economise space, the crank shaft is placed alongside the cylinder, and the movement is transmitted vertically upwards from the piston-rod through a beam and connecting-rod; the stroke of the piston and diameter of circle described by the crank are about in the proportions of two to one. The cylinder is closed at the top, where admission takes place, and open at the bottom. Gas and air enter through a slide valve worked by a cam on the main shaft, and held back by springs. As soon as a series of holes in the slide are covered by another series in the valve face, the out stroke of the piston draws in the gas and air. The mixture is ignited by a flame carried in a cavity of the slide, and lit after each explosion by an external light; the exhaust on the opposite side of the cylinder is worked by a separate cam. Thus during the first half of the down motor stroke, the charge of gas and air is drawn in, explosion and expansion occupy the second half, and the return stroke drives out the products of combustion. The cylinder is water-jacketed in the ordinary way. In another and apparently an earlier horizontal type of this engine, described with drawings by Schöttler, cylindrical air tubes, open above and below, are carried through the jacket to keep the water cool. The gas consumption of this engine is said to be 49 cubic feet per I.H.P.

* *Traité Théorique et Pratique des Moteurs à Gaz.* Par Aimé Witz. Paris, 1892.

per hour. A drawing will be found in Witz, p. 229. A description of the Bénier hot air engine is in Part II.

**Forest.**—The Forest engine, brought out in France in 1883, differs very little from the Bénier, except in one respect. Instead of a water jacket, the external portion of the cylinder is surrounded with deep ribs in the form of a screw, giving a large air-cooling surface. The cylinder is horizontal, and the charge is admitted and ignited at the front end nearest the crank. Power is transmitted from the piston by a lever and connecting-rod to the crank shaft. Gas and air are admitted in the same way as in the Bénier, through openings in the slide and slide face, while the cover, acted upon by the governor, shuts off these openings more or less according to the speed. The ignition and exhaust are also regulated by this slide valve, placed alongside the cylinder; it is worked by a cam on the shaft, and held back by a spring. A projection in the side of the cylinder, opposite the slide valve, causes the mixture to pass in a zig-zag direction before the ignition opening. Here it is ignited when the piston has travelled through one-third of the stroke; an outside flame periodically rekindles the gas jet. Thus admission is effected when the slide valve is at one end, and ignition when it is at the other end of its stroke; when in its central position the gases are discharged into the exhaust. The consumption of gas is about the same as in the Bénier. Drawings of the Forest engine are given by Schöttler and Witz. A much more important type of this motor, driven by petroleum, with reversible action, and intended especially for marine use, is described in Part II. It is to this class of engine that M. Forest has more particularly devoted himself.

**Ewins and Newman.** — Another small non-compressing single cylinder horizontal engine, brought out in 1882 by Ewins and Newman, is distinguished by its somewhat peculiar method of ignition. By the forward stroke of the piston, gas and air are drawn into a mixing chamber at the back of the horizontal cylinder, from which the chamber is separated by a flap valve. The charge is ignited by an outer flame, as soon as a slit in a notched revolving disc, worked by a catch from the crank shaft, is brought to face a similar opening at the back of the cylinder opposite the flame. The exhaust valve is also opened by [illegible] main shaft, and the return stroke expels the produc[illegible] bustion. The engine is evidently constructed to r[illegible] speed than is usual with such small motors.

**François.**—The François, a vertical en[illegible] France in 1879, bears a strong resemblance [illegible] in the latter, the explosion of the charge [illegible] the piston, and the atmospheric pressur[illegible] crank shaft is not in the same line wit[illegible] and the piston works upon it by mean[illegible]

two cranks, and two flywheels. Gas and air are admitted, ignited and discharged at the bottom of the cylinder. There are two slide valves, one within the other. The larger one, containing the openings for the exhaust and the igniting flame is hollow, and held against the side of the cylinder by the slide cover and lateral cheeks. The smaller valve is solid, and there is a space between the two, varying with their position. Both valves work to a certain extent independently of each other. As the smaller moves, gas and air are admitted from the cover through the openings left between the valves, and pass to the cylinder.

**Warchalowski.**—All these small engines belonged to the older non-compressing types, but an interesting little compression engine, designed by Warchalowski in 1884, and made by Hörde & Co., of Vienna, was shown at the Antwerp Exhibition in 1885. It was compact and carefully designed, and differed very slightly from the Otto. The vertical cylinder was at the top. The governor regulated the supply of gas, by means of a projection, acting on the admission valve for a longer or shorter time, according to the speed.

**Noël.**—Several small engines obtained a certain reputation in France, and a few are still made. One of the best is the Noël, brought out in 1888, and shown at the Paris Exhibition in 1889. It is remarkable because, like the Warchalowski, it is one of the few four-cycle engines constructed for small powers, from ¼ H.P. upwards, and using compression. As in the "Economic" motor, there is one cylinder, kept cool externally by radiating ribs. In one type the piston works horizontally, and drives the main shaft below it through a beam and crank. The admission and distribution valves are simple lift valves, instead of the ordinary slide valves. They are driven by an auxiliary shaft, geared 1 to 2 from the main shaft. Air is drawn in automatically from the base of the engine, and ignition is obtained by the electric spark, the governor when required wholly cutting off the admission of gas. Another vertical type is also made, and drawings of both are given in Witz, p. 324. The engine can be driven with carburetted air.

**Durand.**—The Durand, a four-cycle horizontal engine, also exhibited at Paris in 1889, is adapted for working either with gas or carburetted air, and the inventor proposes to drive it with gas when small powers are required, and with carburetted air for high powers. Carburetted air is air highly charged with volatile petroleum vapour. The engine will be described among the petroleum engines, and one point only needs to be mentioned here. Ignition is by the electric spark, and M. Durand has utilised an idea first suggested in Germany. The two wires are attached, the one to a metallic point, the other to a toothed wheel, making one revolution for eight of the motor crank. The point rests against

the wheel, and a spark is produced each time it slips from one tooth to the other. By this friction of the two parts in contact, the metal is kept clean, and there is no danger of the spark failing.

**Mire.**—Another small engine, the Mire, made from $\frac{1}{4}$ H.P. to 2 H.P., was also brought out in 1889. Like the Clerk it has a motor and pump cylinder, and an explosion at each revolution. It is one of the very few gas engines, the action of which can be reversed, and the engine worked either backwards or forwards. This is rather a difficult operation, and gas engines are, therefore, seldom adapted for river boats. The Mire can be driven with gas or petroleum.

Two other small French engines, the Laviornery and the Étincelle, have no special distinguishing features. The first is a non-compression vertical engine, invented in 1880. The second, made by Gotendorff & Cie. of Paris, is a four-cycle horizontal compression motor, with electric ignition, and a hollow base serving as a water jacket, as in the Wittig and Hees engine. Both were exhibited in Paris in 1889.

**Baldwin.**—An interesting and more important engine than the two last is the "Baldwin," introduced from America in 1883. Like the Mire it is of the Clerk type. It has one horizontal cylinder divided into two parts, the back forming the motor, and the front the pump end. Gas and air enter the front, and are thence compressed into a reservoir. An automatic valve is lifted as soon as the pressure in the cylinder is reduced, and admits the compressed gases from the reservoir into the combustion chamber at the back of the cylinder, with which the chamber communicates only through a small aperture. Here the explosion takes place, and the ignited mixture enters the cylinder exactly in the centre, the smallness of the opening preventing its dilution with the products of previous combustion. This arrangement has been superseded in later engines by an apparatus called a "retarder," and the inventor maintains that none of the fresh charge escapes with the exhaust gases. Ignition is effected by the electric current, from a small dynamo driven from the main shaft. To generate the spark at starting, there is a second pulley to the dynamo, smaller in diameter, and revolving more rapidly than the ordinary driving wheel, which is used until the engine is in full work. Three different methods are employed to regulate the speed, first, by diminishing the volume of the mixture, secondly, by partial, and thirdly, by total [illegible]ion of the gas, according to the greater or less excess [illegible] The ball governor acts on the admission valve; the [illegible] by a water jacket, and works with great regu[illegible] of the Baldwin engine is given by Witz, p. [illegible]

**Various.**—Other engines which scarcely [illegible] their invention were the Lindley (1882) [illegible]

cylinders; the Northcote, in which the steam generated in the water jacket was utilised to increase the pressure; and the Laurent, employing a regenerator. Three attempts were also made, about 1883, by Fielding, Bull, and Butcher, to construct reversible engines, but without much success. Butcher further proposed to regulate the length of stroke by the governor. In the Alliaume engine the cylinder was cooled by vertical pipes in which air circulated constantly. Other engines were Linford, 1878; Funck, 1879, the first engine to use ignition by a hot tube; Maxim, 1883; and Taylor, exhibited in the English section of the Paris Exhibition of 1889.

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## CHAPTER VII.

## THE OTTO GAS ENGINE, 1876.

CONTENTS.—Original Type—Parts—Slide Valve—Ignition—Distribution—Governor—Stratification—Tube Ignition—Modern Types—Trials—The Lanchester Self-Starter.

IT is to Otto, the celebrated German engineer, that the honour belongs of having first produced a practical working gas engine using compression, and giving an economical cycle of operations. The Otto engine was brought out at a time when, in the competition between gas and steam, the balance inclined so much in favour of the latter, that it even seemed possible that gas engines would be driven altogether from the field. The construction of the Lenoir and Hugon engines had been more or less relinquished, on account of the quantity of gas they consumed. Of all their successive imitators, none supplied the long-felt want of an engine working as steadily and economically as steam, always ready for work, where a steam engine could not be used. The Otto and Langen engine, which followed the Lenoir and Hugon, was never popular, owing to its unsteadiness, noise, and irregularity. The inventors were fully cognizant of these defects, and for years they laboured to remedy them, working on the principle of admitting the gas and air at atmospheric pressure. At length, however, to the surprise of the engineering world, they gave up altogether this method of construction, and patented in 1876 an engine, shown at the Paris Exhibition of 1878, which differed considerably from any hitherto made.

**Compression.**—The important innovation introduced in the Otto engine was the compression of the charge of gas and air

before ignition. The advantages of this method have been already described. Beau de Rochas had in 1862 laid down the axiom in his patent, that no gas engine could be economical, unless its cycle included compression of the mixture after admission. Yet, although the extravagant consumption in gas engines was universally admitted, no one proposed to adopt compression as a means of diminishing it, till Otto's engine appeared. Even the inventor himself did not seem to understand the radical nature of the change he introduced. He attributed the reduction in the consumption of gas and the popularity of his engines, not to compression, but to the stratification of the charge as it entered the cylinder. The novel method of admission and ignition was expressly protected in the patents. Whatever the cause, the success of this engine was from the first undoubted, and practically, for many years after it was brought out, few others were sold to any large extent. For this reason, and on account of its excellent design and workmanship, it will be useful to consider carefully the constructive details and working of the Otto engine, although it was patented as early as 1876.

**Original Otto.**—In this motor, the whole cycle advocated by Beau de Rochas is effected in one cylinder, in accordance with his patent. The cycle is divided between four piston strokes, two forward and two back (two revolutions), and one explosion or motor impulse is obtained for every four strokes. The original type of the engine is horizontal, and the end of the cylinder nearest the crank is open. The first stroke of the piston towards the crank (forward) draws in the charge; the second stroke (return) compresses it, and ignition follows at the inner dead point. In the third stroke (forward) the force of the explosion drives the piston, and in the fourth stroke (return) the products of combustion are discharged. The third is the only motor stroke, in which the pressure of the gases produced by explosion causes them to expand, forcing out the piston, and performing actual work. All these operations are carried out and completed at the end of the cylinder away from the crank, and on one side of the piston only.

At this working end there is a large clearance space, comprising about four-tenths of the whole volume of the cylinder, into which the charge is compressed, and where ignition takes place. As the piston does not enter this clearance, the gases of combustion can never be completely expelled, but a portion is always left in the compression space to mingle with the incoming charge. Otto considered that it was an advantage thus to retain a part of the products of combustion, to act as a cushion against the piston, and deaden the shock of the explosion. As only one motor impulse is given in four strokes, the motion for the other three must be obtained from the impetus of the moving parts. Hence the flywheel [illegible] larger [illegible]ier than usual. There is one other

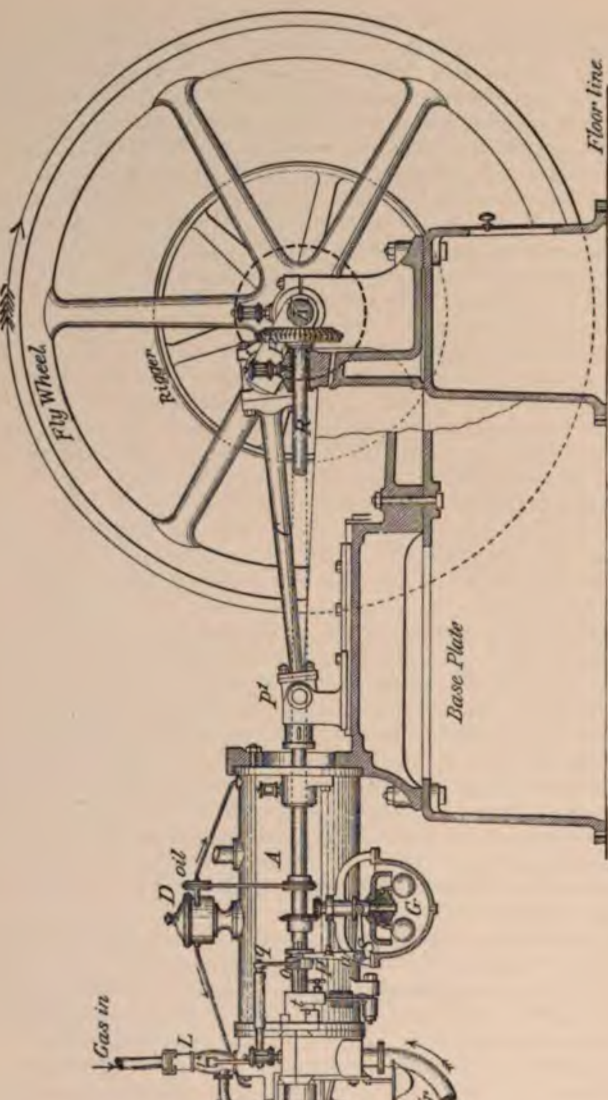


Fig. 22.—Otto Engine, 1876 Side Elevation.

peculiarity of structure to be mentioned, in studying the original Otto type. In most gas motors the charge itself is carried past

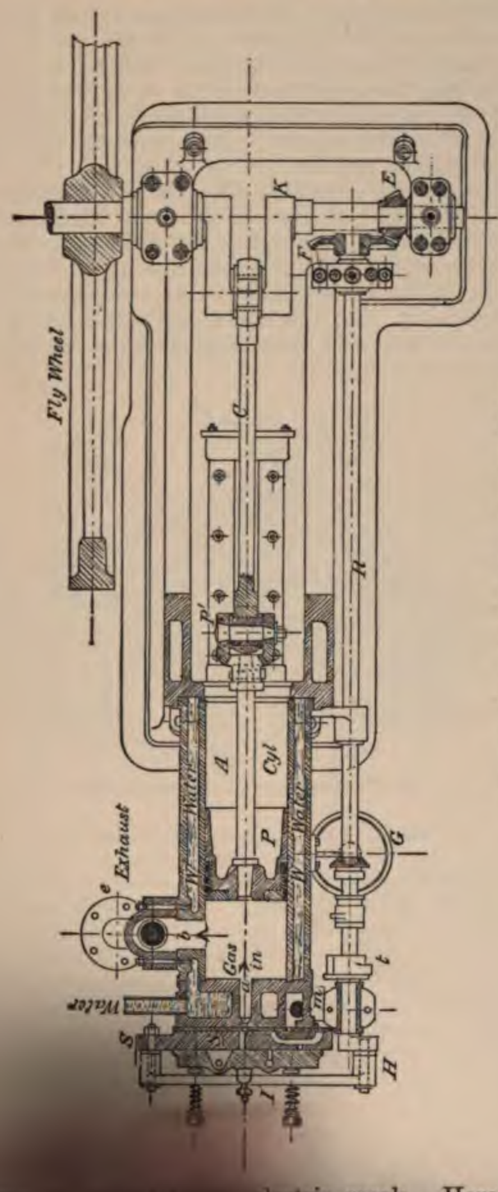


Fig. 23.—Otto Engine, 1876—Sectional Plan.

the flam[illegible] electric spark. Here the gas is
suppli[illegible] purposes through separate pipes.

There is first the supply pipe, providing gas to mix with air for the charge, and controlled by the governor; another for the permanent outside flame; and lastly, a branch pipe feeding a small intermediary chamber in the slide valve, which communicates first with the outside flame, then with the compressed mixture, and fires the charge. The arrangement has been modified in the later engines.

Fig. 22 gives a side elevation, Fig. 23 a plan of an 8 H.P. motor, and Fig. 24 an end view of the Otto engine. The different parts are similarly lettered in the three drawings. A is the motor cylinder, and P the piston, shown in Fig. 23 at its furthest point in the in stroke, with the compression or clearance space behind it. At the crank end the cylinder is open. The piston-rod is keyed to the crosshead P′, to which the con-

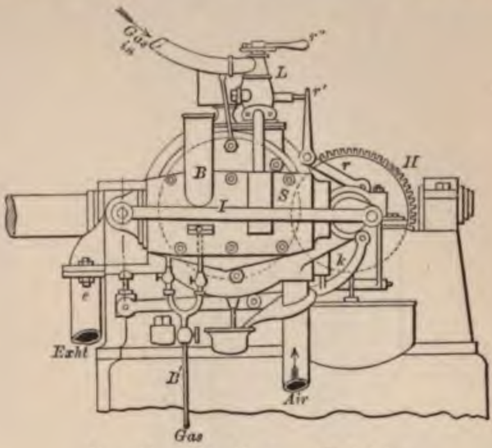


Fig. 24.—Otto Engine—End View.

necting-rod C, working on to the crank shaft K, is also attached. R is the counter shaft, driven by the wheels E and F from the crank shaft, and revolving at half the speed of the latter. This shaft R has many functions to perform. Through a crank H and small lever I it drives the slide valve S, where the charge is admitted, ignited, and exploded. Below is G the ball governor acting upon the gas valve L, and regulating the supply; a cam and tappet *t* upon the counter shaft open the exhaust valve *e* once in every revolution; and, lastly, a strap from it drives the oiling gear D above the cylinder, and supplies oil as long as the engine is working. The cylinder is surrounded by a water jacket W. It has two openings, *a* and *b*—*a* is the charging port, filled first with gas and air at atmospheric pressure from the distributing chamber in the slide valve, and then with part of

the compressed charge, and through this port a tongue of flame shoots into the cylinder, and explodes the remainder; *b* is the opening for the exhaust, and the gases of combustion pass out at *e*. Below at *m* is another opening through which air is admitted into the slide valve, mingles with the gas, and is carried forward until, at *a*, it enters the cylinder.

In Fig. 24 the double branching of the gas pipe to supply the permanent outside burner, and the temporary flame, is seen at $B_1$. The slide valve S is worked by crank H and lever I; *e* is the exhaust opened by lever *k*, and the cam *t* on the counter shaft. The governor works upon the gas valve L by a series of levers, *r*, *r'*, while a handle at *r''* regulates the admission of gas to the valve from the rubber gas bag.

**Slide Valve.**—The slide valve of this engine is an ingenious piece of mechanism. There is first the face next the cylinder,

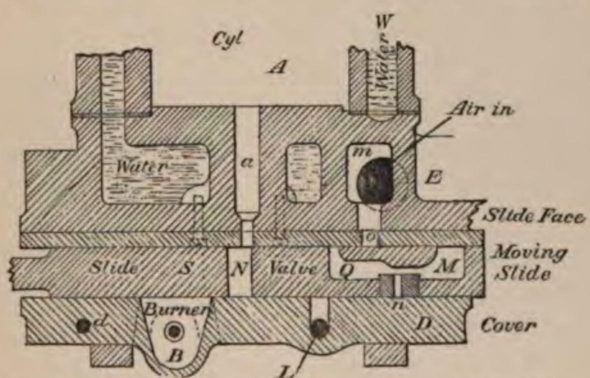


**Fig. 25.—Otto Engine, 1876—Sectional Plan of Slide Valve.**

secondly, the valve proper, and, thirdly, the cover on the outside; the latter is held against the valve by springs and screws. The slide valve alone is driven to and fro; the other parts are fixed. Fig. 25 gives a sectional plan of the three parts, and their connection with the cylinder. Here A represents the cylinder, E the slide face, S the slide valve, and D the cover. W is the water jacket, *a* the charging port introducing the mixture into the cylinder, *m* the opening in the slide face for admitting the air, which passes at [illegible] to a chamber in the slide valve with three openings, Q and [illegible] nd *n* opening to the slide cover. Shortly after, as the slid[illegible] passes from right to left, the gas is admitted from L in [illegible] r, through *n* into the chamber. [illegible] ame direction, the slide next [illegible] ber opposite *a*, and its con- [illegible] to be there compressed by

Meanwhile, at the other end of the slide valve, a different series of operations have been taking place at the same time. At B is the permanent burner in the slide cover, open to the atmosphere. While the slide valve passes from right to left, the chamber N is brought opposite B, but as it contains no gas no ignition occurs. But as soon as it reaches *d*, gas from the third pipe is introduced into it through a grooved hollow in the cover. Before the slide valve commences its return movement, and while the mixture is being compressed in the cylinder,

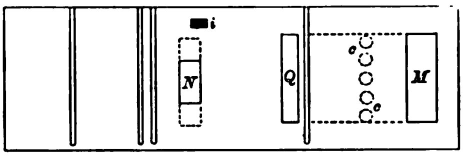


Fig. 26.—Otto Engine—Vertical View of Slide Valve.

the chamber N is filled with gas from *d*, ignites on passing before B, and when brought opposite the cylinder port *a* fires the charge. It is necessary, however, to equalise the pressure of the gas flame and of the charge, lest the flame be blown out.

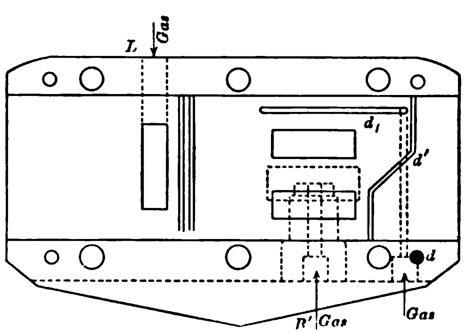


Fig. 27.—Otto Engine—Vertical View of Slide Cover.

As long as the small lighting port is in communication with the atmosphere through B the flame is easily maintained, but as the slide moves onward, and connection is cut off, it begins to fail. Therefore, before it reaches *a*, a hole is passed in the slide face, communicating through a T-shaped passage with the charging port. A small portion of the compressed charge passes through it to the flame in N, and establishes an equilibrium of pressure between the mixture in the cylinder and the flame, before the latter reaches and fires the charge.

Figs. 26 and 27 give a vertical view of the slide and sli ver. In the latter L is, as before, the pipe to admit the r

supply of gas, $B_1$ is the smaller gas pipe feeding the permanent flame B, Fig. 25, which burns at the bottom of a chimney. Through another small pipe the gas passes at *d*, Fig. 27, and through the grooved passage *d′* to the lighting chamber N, Fig. 26. Above this chamber is the hole at *i* through which, and a passage in the slide face, communication is established between the cylinder and the light, as soon as the slide passes the opening of the passage. At *c c*, Fig. 26, are the holes for the gas entering the admission and distribution chamber M Q. Figs. 28 and 29 show a vertical section of the slide valve and cover, with the arrangement of the ignition flame. The parts are lettered as before. N is the lighting chamber in the slide, B the

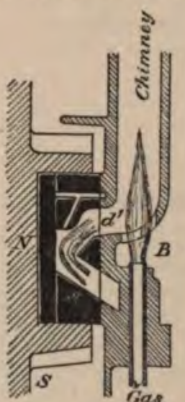

Fig. 28.—Ignition Flame and Slide Valve.

Fig. 29.—Ignition Flame and Slide Cover.

permanent burner in the slide cover. In Fig. 28 the flame at N is shown while being formed. Air enters from below, gas through the groove *d′*, corresponding with the opening *d* in the slide cover, Fig. 25, and passes through this T-shaped channel into N. The chamber being in communication with the flame burning in the chimney, the charge in it is ignited. Fig. 29 gives a view of the intermediary flame in chamber N, after it has been cut off from the outer burner, and from the gas pipe *d*. The T-shaped passage *d′* here opens on the other side into the cylinder port through *i*, and a small portion of the compressed charge passes through into N. Shortly after, the port is brought opposite the cylinder port *a* and ignition follows. Thus during one piston stroke three operations take place, and the slide valve has to [illegible] the intermediary flame, equalise the pressure [illegible] rge in the cylinder, and ignite the latter. [illegible] these various actions are timed to [illegible] a diagram of the proportional

movements of the motor crank, the counter shaft, and the slide valve. The Roman figures represent the positions of the crank, the Arabic figures those of the counter shaft, while the letters *a*, *b*, *c*, *d*, show the movement of the slide valve.

As the motor crank moves from I. to II. in the direction of the arrow, the crank on the counter shaft which is set at an angle

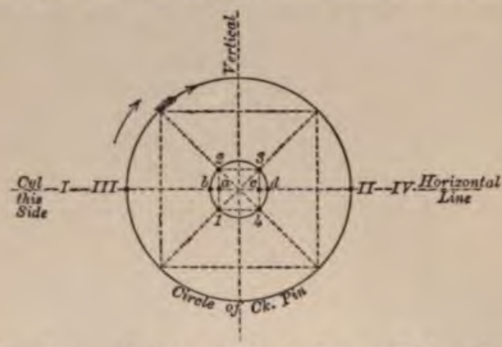


Fig. 30.—Otto Engine—Positions of Crank, Counter Shaft, and Slide Valve.

of 45° behind it passes from 1 to 2, and the slide valve moves from *a* to *b* and back again. During this time the piston moves out, and the fresh charge is drawn at atmospheric pressure into the cylinder. Fig. 31 gives this position at A. Air is admitted at *m*, gas at N, and both after mixing in chamber M Q (Fig. 25) pass through *a* into the cylinder. The next crank movement completing the first revolution is from II. to III. (Fig. 30); the

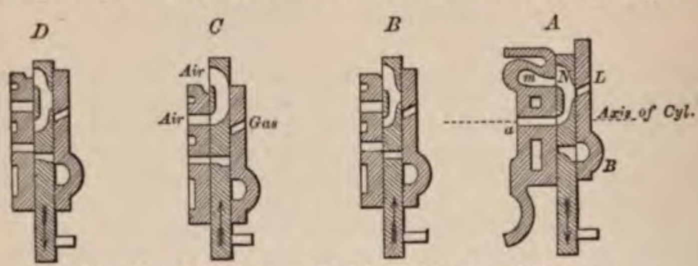


Fig. 31.—Otto Engine—Positions of Ports and Passages.

counter shaft moves from 2 to 3, the slide valve from *a* to *c*. Fig. 31, B, indicates the position of the slide valve. All the ports of the cylinder are closed, while the piston compresses the charge. The lighting chamber is brought opposite the permanent flame and fired, and through the port for equalising the pressure, part of the charge in the cylinder is also compressed into it by the return movement of the piston. Position III.

(Fig. 30) represents the inner dead point; ignition and explosion take place, and drive the piston through its second forward and only motor stroke. The crank shaft revolves from III. to IV., the counter shaft from 3 to 4, the slide valve passes from *c* to *d* and back again. Fig. 31, C, shows the progress of the slide during and after the ignition of the charge. From IV. to I. the crank completes its second revolution, the counter shaft passing from 4 to 1 concludes one revolution, and the slide valve moves from *c* to *a* and takes up position D (Fig. 31). All the admission ports are closed to the cylinder, while the products of combustion are driven out through the exhaust by the second return stroke of the piston.

By this arrangement air enters the mixing chamber M (Fig. 25), and is passed on into the cylinder, during nearly the whole of the admission stroke, but gas is only admitted during the latter part. The two ports are so proportioned that the ingress of air is first cut off, and gas enters alone at the end of the stroke. The effect of this distribution on the stratification of the charge will be discussed further on.

Fig. 32 gives a view of the exhaust valve. The lever opening it, K, shown also in Fig. 24, passes beneath the motor cylinder A, and is worked by a cam, *t*, on the counter shaft R. The end of the lever is held against the counter shaft by a spring. At a given moment the cam *t* presses one end of the lever down, and the other raises the lifting valve *s'*; *b* is the opening into the cylinder, and *e* the discharge into the exhaust. When valve *s'* is raised, the action of the piston drives the products of combustion through *b* and *e*. The cam being one-quarter the circumference acts upon the valve during one-quarter of a counter shaft revolution, or one stroke of the piston. A second cam upon the other side of the shaft can also be adjusted to push down the lever, and hold open the valve, when starting the engine, during the compression as well as the exhaust stroke. This method of diminishing the pressure in the cylinder while starting has been adopted in other engi[illegible] besides the Otto. The second cam is easily disconnect[illegible] the shaft, as soon as the engine is at work.

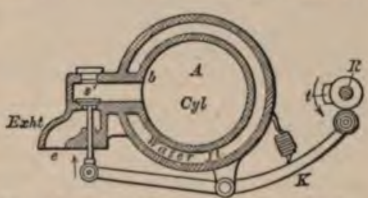

Fig. 32.—Otto Engine—Exhaust Valve.

The speed of the engine is regulated as shown in Fig[illegible] pp. 76, 78. Upon the counter shaft R is a socket wi[illegible] having a similar action to the exhaust cam. Wh[illegible] revolving at ordinary speed, this tappet regular[illegible] pushes up one end of the lever *q*, resting upon i[illegible] of which terminates in the rod *r*, opening t[illegible]

valve L. But if the speed increases, the balls fly out and push up another small lever *u*, which, forcing the socket to one side, causes the tappet *o* to miss the end of the lever *q*. Nothing but air is admitted, and no explosion follows until the speed is reduced, and the tappet being again in position acts upon the gas valve. The handle *s* (Fig. 22) is intended to raise the balls only when starting the engine, and falls back automatically after the first explosion.

Two methods were available for regulating the speed, either to cut off wholly the supply of gas, or to decrease the quantity admitted; the former was preferred as being more economical. No gas could then pass unburnt through the cylinder, but, as an explosion was missed every time the gas valve was closed by the governor, the speed became irregular. Otto was obliged, therefore, to modify the governing gear when the engine was used to drive dynamos for electric lighting, where a very steady speed was required. Instead of the tappet, a cam with various steps acted upon the lever *q*. When the speed fluctuated within slight limits, the cam opened the gas valve for a longer or shorter time, and varied the strength of the charge. The explosions were sometimes weak, sometimes strong, but never wholly missed, unless the speed was so greatly increased that the wheel of the lever slipped quite off the cam. Latterly, for small motors, Otto adopted the pendulum type of governor, which is frequently met with in modern engines. It consists of an oscillating weight at the end of a rod, swinging backwards and forwards with the motion of the engine and of the slide valve, to which it is attached. As long as the speed is normal, a horizontal rod, connected to the pendulum, fits at each revolution into the notched end of the valve-rod opening the gas valve. But if the speed and the motion of the slide valve increase, the swing of the pendulum cannot overtake them. The weight shifts the rod out of position, a miss fire occurs, and no gas is admitted until the speed of the engine is reduced.

*Sectional Elevation.*

Fig. 33.—Otto Gas Engine—Oiling Apparatus.

The lubrication of the Otto engine is simple and ingenious. Great care was necessary in oiling all the parts, especially the slide valve. Fig. 33 shows a vertical section of the oiling apparatus. An external view with the two lubricating pipes is shown at D, Fig. 22, p. 76. This apparatus is worked by means of a small pulley, *a*, and a strap on the counter shaft. The cup is filled with oil into which a small wire, *b*, on the same shaft as the pulley, dips at every revolution. The drop is wiped

off on a fixed pin, *c*, placed over a trough. From the trough it runs into one of the two pipes, and is carried either to the piston or the slide valve. Sometimes this arrangement is made in duplicate, and the cup divided vertically. Two kinds of oil can be then used at the same time, the better quality for lubricating the slide valve, and a coarser oil for the piston. In this apparatus the oil is kept cool, and lubrication is automatic and continuous.

For starting small power engines, the additional cam to keep the discharge valve open during compression as well as exhaust was found sufficient. But the Otto motors were soon applied to larger powers (over 20 H.P. nominal), and it then became impossible to start them without a special apparatus. The German Otto firm often use a small, to start a larger gas engine. In the two-cylinder 30 H.P. gas motors driving the dynamos lighting the Cologne Theatre, a small 2 H.P. engine is employed to set them in motion; when they are once started the little engine stops.

Few engines more ingeniously constructed than the Otto have yet appeared, and even now, when so many later motors have been brought out, it is still one of the most economical. For many years after its introduction in 1876 it was almost the only practical gas engine made. More than 30,000 engines were sold in about ten years, and according to the German firm 35,000 engines, with a total of about 150,000 H.P. had, up to 1892, been constructed by them.

Otto himself attached, as we have said, the greatest importance to his system of admitting the charge. The slide valve is so constructed that pure air enters first, and passing into the cylinder mingles with the products of combustion left from the previous charge, which the piston (as it does not enter the clearance space) cannot expel. Hence, next the piston, there is said to be a weak mixture, which is intended to deaden the shock, to retard combustion, and to take up some of the heat developed by the explosion. Gas next enters the slide valve and mixes with the air, and this layer, on reaching the cylinder, forms a dilution of medium strength, the proportions being about 7 of air to 1 of gas. Finally, by the movement of the slide valve pure gas alone, without any admixture, is admitted into the cylinder. It is this gas which, through the grooved passage in the slide valve, feeds the burning light, and causes it, as Professor Witz says, to shoot into the poorer mixture like a tongue of flame. Thus there are three strata in the cylinder, of three different degrees of richness, the mixture nearest the piston being so diluted that it will not ignite, except by the force of the [illegible]. The flame is supposed to leap from one layer to [illegible] the slow combustion so much desired by Otto. [illegible] scientific men supported his theory of stra[illegible] were

strongly opposed to it. Perhaps the best proof that it does not really take place in the manner supposed, is furnished by the makers of the Otto engine in different countries, who have abolished the slide valve, and substituted admission by lift valve, without any effect on the action of the engine.

The patents for the Otto engine, which have now expired, were formerly acquired in England by Messrs. Crossley Brothers, of Manchester; in France, by the Compagnie Française des Moteurs à Gaz; in America, by Schleicher, Schumm & Co., of Philadelphia. The German firm have long been established near Cologne.

Several of these firms, while adhering to the principle of the original type, have made many alterations in the working details. Messrs. Crossley have introduced ignition by a hot tube, instead of by a flame carried in the slide valve. Fig. 34 gives two views of this method of ignition, as used for many years; it has recently been again modified. C is the passage into the cylinder, T the cast-iron tube, and R the asbestos lining of the chimney. The tube is closed at the top, and kept at a red heat by a Bunsen burner, B. During the compression stroke a cam on the counter shaft lifts the lever L, and pushes up the timing valve E into the port D. No portion of the compressed charge can, therefore, enter the tube, and any burnt gases left in it escape through A into the atmosphere. At the inner dead point, when the piston has completed the compression stroke, the cam leaves the lever L free, E is drawn down by the spring S, and the compressed mixture, rushing into the red-hot tube, is there fired and ignites the charge. G and F are outlet channels for discharging the burnt gases through A. Thus a rich mixture alone enters the tube, and ignition is certain. By this method the pressure of the charge is utilised, and is made to fan the flame instead of blowing it out.

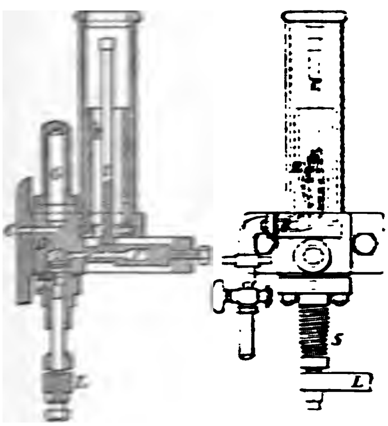

Fig. 34.—Otto Engine—Ignition Tube.

As the Otto engine became more popular, and larger sizes were made, the cost of working it with town gas was found to be heavy, especially on the Continent, where coals are generally dearer than in England. Several methods were introduced for

making gas more cheaply than by distillation from coal. These will be described later on; the system most generally used is Mr. Dowson's cheap gas producer, which, when applied to any engine, reduces considerably the cost of working, as compared with town gas. This gas, usually generated on the spot, is economical only when employed for larger engines. As it is much poorer than lighting gas, it requires to be diluted with a smaller proportion of air; the ratio is generally about 1 of Dowson gas to $1\frac{1}{2}$ of air. In the Otto engine certain modifications in the size of the gas and air valves were formerly necessary. Generally speaking, however, when it is desired to drive a motor with cheap or Dowson gas, the makers prefer to supply an engine especially adapted to the purpose.

For powers over 30 H.P., the makers of the Otto now often use engines having two cylinders side by side, and two sets of valves, driven from a single auxiliary shaft placed between them. One governor regulates the speed. The two motor cranks are in the same plane, working on one shaft, and the two piston rods are 180° apart. The forward stroke of one is the motor expansion stroke, while, at the same time, the other piston draws in the charge. In the two following strokes, the one piston compresses the charge, and the other drives out the products of combustion. Thus a motor impulse is obtained alternately from each piston, for every revolution of the crank shaft. Messrs. Crossley make engines of this type, indicating 170 H.P.; the German firm bring them out up to 200 H.P. These twin-cylinder engines are also used for electric lighting, on account of their regularity in running. They can be worked either with coal gas or cheap gas. A two-cylinder engine indicating 30 H.P. was shown at the Electrical Exhibition at Frankfort in 1891. Each cylinder was complete in itself, with hot tube ignition and admission valves, and could be worked alone. Gas was supplied from a receiver controlled by the governor, which could be disconnected from one cylinder, and made to act upon the other only, if less power was required. In all modern Otto engines hot tube ignition is used. Messrs. Crossley also make an engine, as shown in Fig. 35, with two cylinders opposite each other, working on to one crank.

In 1879 Otto made an attempt to apply the compound principle of expansion to gas motors, and constructed an engine with three cylinders and pistons, all single-acting. Between the two cylinders, in which explosion took place alternately, a third was introduced where the charge was further expanded. The cranks of the three pistons were set at such an angle to each other that explosion was continued in [illegible] third cylinder at each forward stroke, while the first of [illegible] other pistons drove out the products of combustion, [illegible] second drew [illegible] the charge. Thus the expanding cylin[illegible]d alternat[illegible]

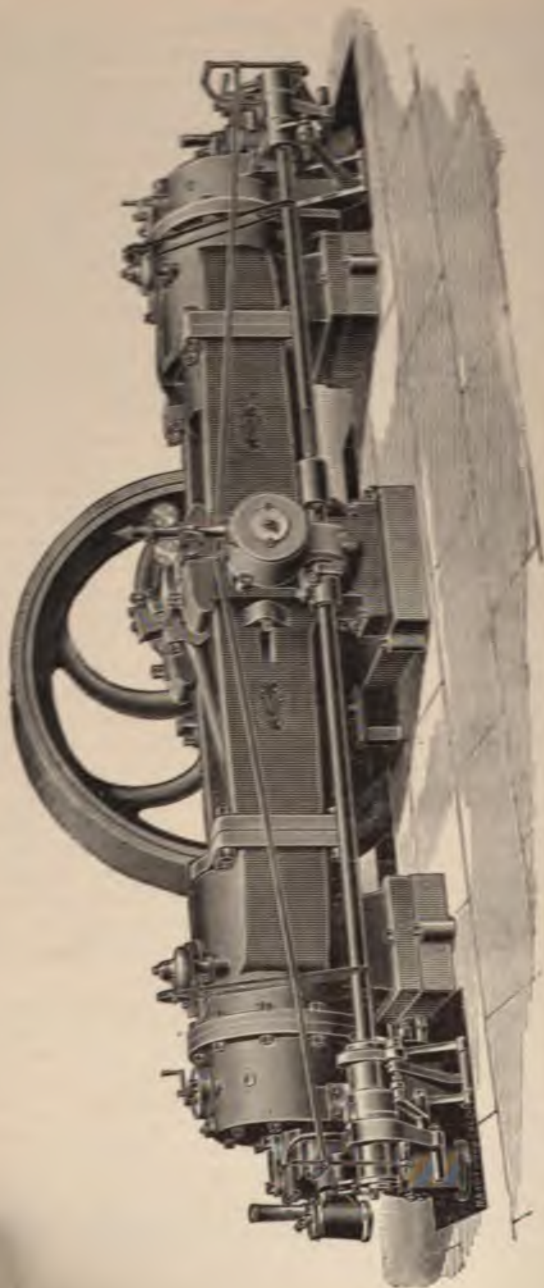

Fig. 35.—Otto-Crossley Engine. Two cylinders and one crank.

with the others in each consecutive motor stroke, receiving the charge for expansion first from one, then from the other, and an impulse for each crank revolution was obtained. This type of construction seems to have been soon abandoned, and Professor Witz is of opinion that the friction and the greater cylinder wall surfaces exposed to the hot gases, and carrying off their heat, would destroy the advantage of increased expansion.

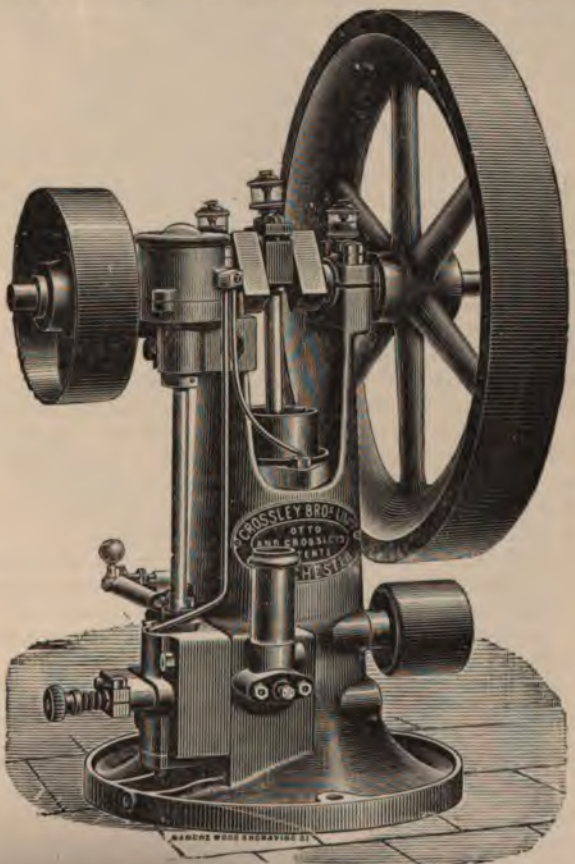

Fig. 36.—Otto-Crossley Domestic Motor.

For large and mediu[illegible] [illegible]rs, the horizontal type of engine i[illegible] [illegible]r, soon arose for small, light [illegible] [illegible]he "Domestic Motor," Fig. [illegible] [illegible]ut to meet this require- [illegible] [illegible]act than a horizontal

engine, and can easily be transported. It has few parts, and these are as simple as possible. A pendulum governor acts on the gas valve through a vertical rod with knife edge, catching at a given moment into a projection, which lifts the valve admitting the gas. If the speed increases, the pendulum swings back this rod, the knife edge is missed, the gas valve is not opened, and no explosion occurs. In this engine, as made by Messrs. Crossley, gas and air are admitted through a rotatory valve into the cylinder. In the German type, the ignition tube is not shut off by a valve, but is always open to the cylinder, and a certain quantity of the gases of combustion, therefore, remains permanently in it. The compression stroke forces this residuum and part of the fresh charge up the narrow passage leading to the hot tube, and causes ignition. This type of motor is made in sizes up to 1½ H.P.

The Otto engine, described in detail in the beginning of this chapter, is of the original type brought out in 1876, and various modifications and improvements have since been made, especially by Messrs. Crossley. In their motors, as now constructed (1893), the slide valve has been abolished for all sizes of engine, and air and gas are separately admitted through lift valves, worked by cams on the counter shaft. The exhaust lift valve, worked by a cam and levers, has been retained. The modern ignition by hot tube, instead of a flame in a cavity, has been described already. Communication between the cylinder and the tube is generally made through a timing valve, worked by a cam. A patent pendulum governor or a ball governor is used. The counter shaft is driven by worm gear from the crank shaft, the oiling is practically the same as that of the original type.

Most Otto engines are provided with a safety apparatus to prevent their starting backward, and many have a special starting gear. With the exceptions above mentioned, all are made horizontal. As a rule, for the smaller sizes they indicate double, and for larger sizes two and a-half times their nominal horse-power. Thus a single cylinder 20 H.P. engine, nominal, will indicate up to about 50 H.P.; a double cylinder 32 H.P. nominal will indicate 82 H.P. Messrs. Crossley also make 40 H.P. engines indicating 98 H.P.; larger sizes have been described. In all these engines, the power obtained is based on the use of town gas. A special horizontal type is made for electric lighting, running at 250 revolutions per minute. A drawing of it is shown at Fig. 37. The engine is in sizes from 6 to 14 B.H.P., and supplies power for 50 to 112 incandescent lamps. The smaller sizes up to about 4 nominal H.P. run at 200 revolutions per minute; larger up to 14 H.P. nominal at 170 or 180 revolutions, and the largest motors at 160 revolutions per minute.

According to Messrs. Crossley the consumption of Manchester gas for driving their engines varies from 17 to 25 cubic feet

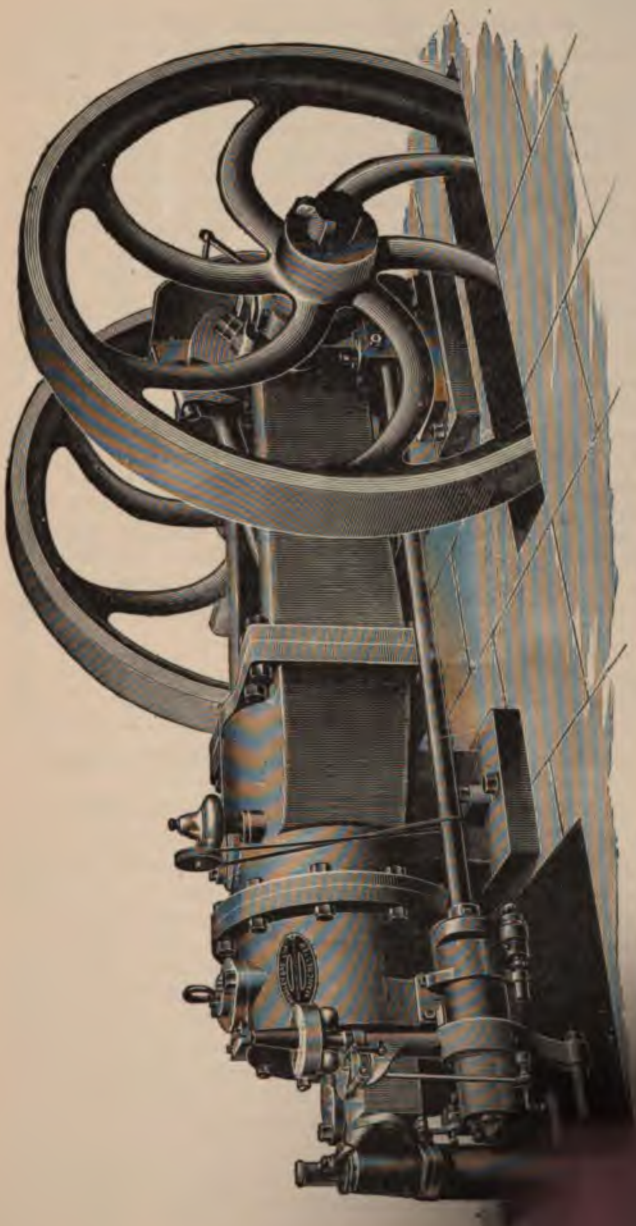

Fig. 37.—Otto-Crossley Engine for Electric Lighting.

per I.H.P. per hour, in proportion to the size of the engine. With Dowson gas the consumption of anthracite coal is from 1·1 lb. to 1·4 lb. per I.H.P. per hour, and of coke 1·5 lb. At the Crossley Works Dowson gas is used to furnish from 200 to 300 I.H.P., and no steam power is employed.

More experiments have probably been made on the Otto than on any other gas engines. Details of these will be found in the table, p. 400, but a few of the more important are here summarised. The earliest published trials on an Otto engine were carried out by MM. Brauer and Slaby, in Germany, in 1878. The engines indicated 3·2 H.P. and 6 H.P.; the first ran at 180 revolutions, the second at 159 revolutions per minute. Between 38 and 40 cubic feet of gas were used per I.H.P. per hour. This was a large consumption for an Otto engine, though at the time the economy, as compared with the expenditure in other motors, was striking. From this period for the next ten years the consumption of gas gradually diminished, as various improvements were effected in the engines. The amount of gas used also varied inversely with the size of the engine tested. In an important experiment* by Dr. Slaby in 1881 on a 4 H.P. engine, making 157 revolutions per minute, the gas consumption was 28·3 cubic feet per I.H.P. per hour. An indicator diagram of this trial is given at Fig. 38. Another, carried

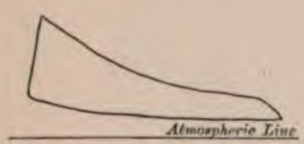


Fig. 38.—Otto Engine—Indicator Diagram.

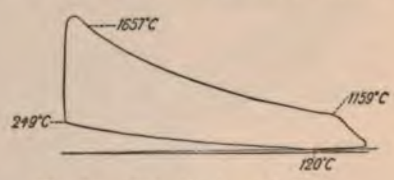


Fig. 39.—Otto Engine—Indicator Diagram.

out in America by Messrs. Brooks & Steward, under Professor Thurston's direction (diagram Fig. 39), was on an engine giving 9·6 I.H.P.; the number of revolutions was 158, and the gas consumption per I.H.P. per hour, 24·5 cubic feet. The greatest economy appears to have been obtained in an engine tested by Garrett, of 14·26 I.H.P, consuming 19·4 cubic feet of Glasgow gas per I.H.P. per hour (diagram Fig. 40). An interesting trial is on record, made by Teichmann & Böcking in 1887 on an Otto engine of 50·8 B.H.P., using Dowson gas. The consumption was estimated at 103 cubic feet per hour per B.H.P., equivalent to one quarter that quantity, say 25 cubic feet of town gas (see

* Full details of this experiment will be found in the Appendix to Professor Fleeming Jenkin's Paper on "Gas and Caloric Engines." Lecture delivered before the Institution of Civil Engineers on 21st Feb., 1884.

p. 404). In 1881 a series of trials were made at the Crystal Palace by Professor Gryll Adams, on Otto engines of various powers.

In 1888 an important set of trials of motors for electric lighting was made in London, under the auspices of the Society of Arts. The judges were Dr. Hopkinson, F.R.S., Professor A. Kennedy, F.R.S., and Mr. Beauclerk Tower, and three gas engines were entered for competition, an Otto-Crossley, an Atkinson, and a Griffin. So careful and accurate a series of experiments of different gas engines at the same time and place, and under similar conditions, has not, to the writer's knowledge, been made before. The Otto engine was of 9 H.P. nominal, the Griffin of 8 H.P. nominal, and the Atkinson of 6 H.P. nominal. For the special purpose of electric lighting, the engines were tested according to efficiency under the following heads:—Regularity of speed under varying loads; power of automatically varying the speed; noiselessness; cost of construction, of maintenance, and of fuel. All three engines worked satisfactorily. The

Fig. 40.—Otto Engine—Indicator Diagram.

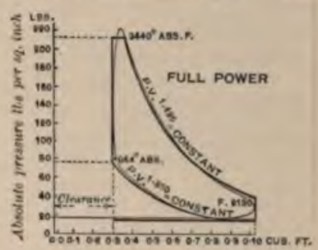


Fig. 41.—Otto Engine—Indicator Diagram.

lowest consumption of gas was obtained with the Atkinson engine, although it was the smallest in size. Comparing the two other motors, the judges gave the preference to the Griffin for regularity of speed, and to the Otto for economy of gas and oil. The gas used (Gas Light and Coke Co.) was carefully analysed. The quantity of jacket water per hour was noted, as also its temperature on entering and leaving the jacket. Each of the engines was tested at full power, at half power, and running empty without load. Indicator diagrams were taken every quarter of an hour, and sometimes every five minutes. Fig. 41 gives a diagram of the Otto engine taken during the trial.

As the engines were all new, and entered for a trial competition, they were, probably, more carefully made than usual. Hence the results were perhaps rather better than those obtained with similar types of engine under ordinary working conditions. The Otto engine used was of the modern kind, with lift valves and tube ignition. Details of the experiments will be found in the

table, but, for comparison, the chief results of the three engines running at full power are given below.

The same gas was used in all the trials.

TRIALS OF GAS MOTORS, SOCIETY OF ARTS, LONDON, SEPTEMBER, 1888.

| Name of Engine. | Atkinson. | Otto-Crossley. | Griffin. |
|---|---|---|---|
| Diameter of cylinder, | 9·5 inches | 9·5 inches | 9·02 inches |
| Length of stroke, | 12·43 inches | 18 inches | 14·0 ,, |
| Indicated horse-power, | 11·15 | 17·12 | 15·47 |
| Brake horse-power, | 9·48 | 14·74 | 12·51 |
| Revolutions per minute, | 131·1 | 160·1 | 198·1 |
| Mean effective pressure (from the diagrams), | 46·07 lbs. | 67·9 lbs. | 54·15 lbs. |
| Quantity of gas per I.H.P. per hour (exclusive of ignition flame), | 18·82 cub. ft. | 20·55 cub. ft. | 22·64 cub. ft. |
| Quantity of gas per B.H.P. per hour (exclusive of ignition flame), | 22·14 ,, | 23·87 ,, | 28 ,, |
| Explosions per minute, | 121·6 | 78·4 | 129 |
| Indicated horse-power for driving engine alone, | 1·67 | 2·38 | 2·96 |
| Mechanical efficiency, | 85°/。 | 86°/。 | 80°/。 |
| To work engine alone, | 15°/。 | 14°/。 | 20°/。 |
| Percentage of total heat of combustion turned into work, or actual heat efficiency, | 22·8 | 21·2 | 21·1 |
| Calorific value of 1 cub. ft. of gas, T.U. (from chemical analysis), | 633 | 626 | 624 |

The **Lanchester Patent Self Starter** is a simple but ingenious device for starting gas engines of any size, with or without compression. The apparatus consists of three small additions to the ordinary working parts of an engine. These are, a tube through which gas is forced into the cylinder, displacing the greater part of the air in it, and mingling with the rest to form an explosive charge; a cock at the top of the cylinder, provided with a small automatic valve, and terminating in a nozzle open to the atmosphere; and a second cam on the auxiliary shaft, to open the exhaust valve during the compression, as well as during the exhaust stroke. The latter now forms a part of many gas engines.

The method of starting is as follows.—The piston being previously stopped, or brought by hand into a position slightly over the incentre of the working stroke, gas is allowed to enter the cylinder through a special nozzle, either at the ordinary pressure of the gas main, or through a little hand pump. At the same

time gas is admitted through another pipe with two branches. One terminates in an external flame, the other communicates freely with the cylinder through the cock mentioned above, in which is an automatic valve, usually held down by its own weight or by a spring, and leaving the passage free. When the pressure in the cylinder exceeds that in the passage, the valve is driven up, and shuts off communication. The gas entering by the nozzle displaces the air in the cylinder, and forces it out through the passage until, the air being gradually expelled, gas follows and ignites at the external flame. The supply of gas being cut off, the velocity of the flame propagation exceeds that of the mixture issuing from the nozzle, the flame strikes back into the cylinder, an explosion is produced, and the piston driven out. The force of the explosion closes the automatic valve. With small engines this is sufficient to start, but in larger motors the second cam actuating the exhaust is brought into play. As the pressure in the cylinder thus falls below atmosphere during the compression stroke, the automatic valve in the passage lifts, and the mixture, admitted in the ordinary way, is ignited at the external flame. At the end of the stroke the pressure in the cylinder rises, and the flame strikes back into the compression space behind the piston.

The working of this apparatus varies according to the size of the engine. To start a large motor, a series of low-pressure explosions are required, until sufficient power has been generated to drive the engine in the ordinary way. The valves, cocks, and the exhaust cam are then easily thrown out of gear by hand. The tube and nozzle for introducing gas into the cylinder may be dispensed with, and the charge admitted through the usual valves. The combustible mixture is then compressed as before into the passage leading to the external flame, ignites, and explodes back into the cylinder.

One modification of the Lanchester apparatus is used to start the Bisschop, and another is intended for engines in which the mixture in the cylinder is already compressed. A double seated valve works in a small chamber filled with the explosive mixture, and communicating with the compression space of the cylinder. When the valve is on its lower seat, communication is cut off, and an external flame plays into the chamber; when the pressure in the cylinder produced by turning the crank by hand forces the valve on to its upper seat, the flame is cut off, and the ignited mixture spreads to the cylinder, and fires the charge. The opening of the exhaust reduces the pressure in the cylinder below atmosphere, the valve is again driven down on to its lower seat, the flame plays into the small auxiliary chamber, and a second explosion against compression is obtained. The force of the explosion is also sometimes used to close the valve.

# CHAPTER VIII.

## THE ATKINSON ENGINE.

CONTENTS. — Principle of Increased Expansion — Differential Engine — "Cycle" Engine—Link and Toggle Motion—Trials.

THE ingenious mechanism of the Otto engine described in the last chapter, and the fact that it was the first to realise the cycle of Beau de Rochas, made it long and deservedly popular. It seemed as if a gas engine had at last been produced, working with the requisite steadiness and economy. But, as time passed, the question arose whether a still lower gas consumption and better design were not possible. Experiments had proved that only about one-fifth of the heat given to the best Otto engine was utilised as power. Defective expansion was one of the chief causes of this loss of heat, and how to remedy it is the problem still occupying the minds of engineers. To increase the length of the piston-stroke enlarges the cylinder volume, and admits more of the charge, and at the same time allows greater scope for the expansion of the gases. It is the proportion of the volume of admission to the total volume, or number of expansions, which may be altered, and the piston made to travel through a shorter distance when admitting and compressing, than when expanding the charge. The solution of the problem presented by Mr. Atkinson is original and ingenious. Practically, the question is treated from a new point of view, though the method had been fore-shadowed in several directions by earlier inventors,—Seraine, Sturgeon, and Martini—but none of them had been able to realise a working success. The numerous experiments made on the Atkinson engine prove that it is also very economical, works well, and requires little attention.

**Principle of Atkinson Engine.**—Mr. Atkinson has introduced two engines, the main principle of which is the same, although carried out in different ways. The whole cycle is performed in one cylinder; there is one motor-stroke in four, and this stroke corresponds to one revolution of the crank only. The four operations of the Beau de Rochas cycle—admission, compression, explosion plus expansion, and exhaust, are effected in four separate strokes of different lengths, and hence the ratio of expansion is independent of the ratio of compression. A special feature of both engines is that the compression or clearance space varies according to the operations taking place in the cylinder, whether the piston be admitting, compressing, or expanding the charge. Like others who have studied the subject,

Mr. Atkinson considered that the two main sources of waste of heat were the exhaust and the water jacket, and he has attempted to reduce these losses by arranging the connection between the piston and the crank, so as to give different lengths of stroke. If the piston travels more quickly, there is less time for the heat to be carried off by the jacket ; if a longer expansion stroke is obtained, the heat and pressure of the gases have more time to act in doing useful work on the piston, before the exhaust opens. The more rapid and longer expansion obtained by Atkinson, after many trials, forms the chief novelty in his engines. He claims to expand the charge to the original volume during one-eighth of a revolution, as compared with half a revolution during which it is expanded in the Otto. In the latter engine the charge is drawn in during one out stroke of the piston, or half a revolution, and expanded during the next, while the crank makes another half revolution, to the original volume,—namely the total volume of the cylinder. In the Atkinson engine, the stroke expanding the charge is nearly double as long as that admitting it, and hence the charge expands to almost twice its original volume. In a 6 H.P. motor the suction or admission stroke is about 6½ inches, the expansion stroke is about 11½ inches. As the whole cycle is effected during one revolution of the crank, this increased expansion is obtained in one-quarter revolution, and expansion to the original volume in one-eighth revolution, or one-quarter the time occupied in the Otto engine. The heat transmitted through the walls to the jacket should be in proportion—first, to the time the wall surfaces are exposed, and secondly, to the differences of temperature between them and the gases they enclose. Rapid and prolonged expansion ought, therefore, to check the waste in both directions. The quick moving out of the piston brings the ignited charge in contact with the walls for a much shorter time, and the heat being absorbed in expansion, by the time the exhaust opens the gases are comparatively cool. Mr. Atkinson maintains that he utilises three times as much heat as Otto in the same time. It is certain that, owing to the way in which the lengths of the piston strokes are proportioned, more complete expansion is obtained, but whether more heat is really utilised than in other motors trials alone must decide.

There is no slide valve in either of the Atkinson engines. The mechanism for admitting and firing the charge is simple, but the link and lever arrangements for connecting the piston and crank are a little complicated. On the whole, both his engines work economically, and the consumption of gas in the later "Cycle" engine, as shown by the Society of Arts' trials, is very low. The modifications introduced are—I. Initial compression into a much smaller space than the original volume. II. Smaller

wall surface exposed in a given time. III. Rapid and continued expansion.

**Differential Engine.**—As early as 1879 Mr. Atkinson took out a patent, No. 3213, for a compression engine of the Otto type, in which ignition was obtained by a red-hot tube. This was one of the first instances of a working engine firing the gas in this way; the same method was employed in the same year

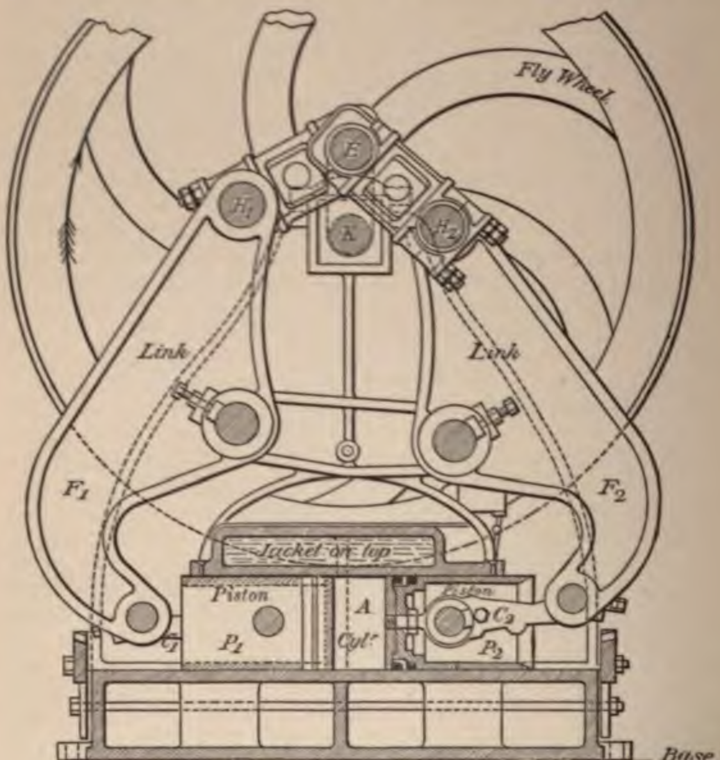


Fig. 42.—Atkinson's Differential Engine.

by Leo Funck. Atkinson soon abandoned this type of construction, and began to work on new lines. Fig. 42 gives a sectional elevation of his first or Differential engine, exhibited at the Inventions Exhibition in 1885. The horizontal motor cylinder A contains two pistons, both working outwards, and ined by their connecting-rods, $C_1$ and $C_2$, to the bent l $_1$ and $F_2$, which act through $H_1$ $H_2$ upon the crank .. Of these two pistons the left-hand one, $P_1$, may b

the pump piston, and chiefly compresses the charge; the right-hand, $P_2$, is the working piston, and effects the greater part of the working stroke, but both pistons co-operate in utilising the explosive force of the gases. There is only one cylinder, open at both ends; during the compression of the charge the pistons hold the exhaust port and the ignition tube closed.

The method of admission, ignition, discharge, and regulation of the speed is simple. Air is admitted through an automatic lift valve, gas through a valve opened by a rod from an eccentric on the main shaft. The rod terminates in a knife-edge acting on the lever of the gas valve, and if the speed be too great the governor, which is driven by a pulley from the crank shaft, shifts the valve-rod out of position, and no gas is admitted. Ignition is by a tube kept at a red heat by an external Bunsen burner. It has no valve, but opens directly to the cylinder through a small aperture. The exhaust, uncovered by piston $P_2$ in its out stroke, is closed by an automatic valve, and opened by the action of the piston. The admission and distribution valves are in front, the exhaust is at the back of the cylinder, which has a water jacket at the top only, as seen in the drawing.

The method by which the two pistons act upon the crank is given in the four positions at Fig. 43, showing the links, the levers, and the movement of the connecting-rods. $p_1$ and $p_2$ are, as before, the pump and working pistons, and $h$ the ignition tube. In the first position, $a$, the two pistons are shown close together, and both at one end of the cylinder. The products of combustion have been completely expelled, and the clearance space between the pistons is reduced to its smallest limits. The energy of motion in the flywheel now lifts the crank, the pump piston $p_1$ moves rapidly to the left, the other piston following it slowly, the automatic admission valves are uncovered at B, and the charge (position $b$) enters between the two pistons, through the openings left in the black lines in the drawing of the outline of the cylinder. In position $c$ the admission valves are closed, the working piston has followed the pump piston rapidly to the further end of the cylinder, and the charge is shut into the diminished volume between them, leaving a relatively small surface of cylinder wall by which the heat can escape. A slight further movement of the pump piston uncovers the ignition tube, the compressed gases enter, the charge is fired, and the working piston moves rapidly out to the extreme limit of the cylinder, uncovering the exhaust valve. The pump piston follows more slowly, driving out the products of combustion (position $d$).

In Fig. 43 the variab[illegible] clearance space is shown, and the action of the pistons upon [illegible] ignition and exhaust valves. The [illegible]med by the movement of the [illegible]n moment with the exhaust [illegible]ge to be fired or expelled.

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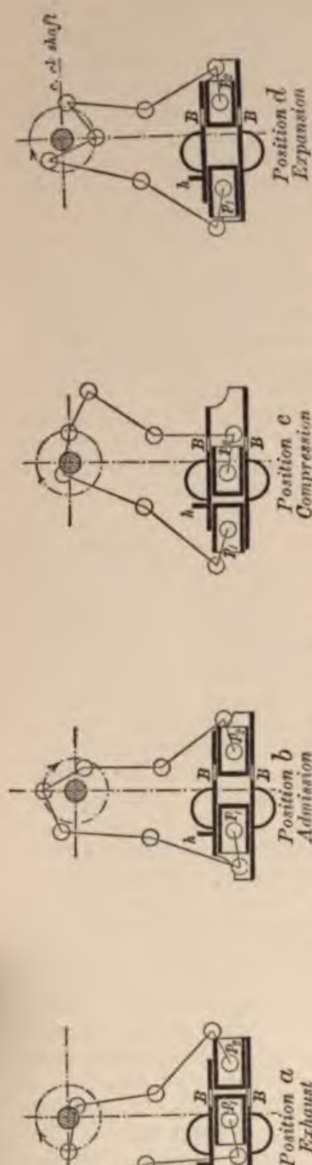


Fig. 43.—Atkinson Differential Engine—Piston and Links, Positions.

The pistons themselves act as slide valves. Between them the functions of admission, compression, expansion, and exhaust are performed in four strokes of unequal lengths. The actual clearance space, into which neither piston enters, is about 1 inch in a 2 H.P. engine. The distances between the pistons during the different operations are as follows:—Admission 3·4 inches (position *b*), Fig. 43; Compression 1·7 inch (position *c*); explosion and expansion 7·6 inches (position *d*); exhaust 1 inch (position *a*). The proportion of the two strokes, or the ratio of admission and compression to expansion and exhaust, is as 2·58 to 4·44.

In theory the action of the Differential engine appears to realise almost complete expansion, but the practical results obtained were not uniformly satisfactory. Professor Schöttler found that the consumption when running empty was very high, and the mechanism of transmission was also defective. The levers, links, and connecting-rods were rather unwieldy, and after a few years' trial of the engine, Atkinson improved upon it by the production of the "Cycle," in which the same principle was retained, embodied in a much simpler form.

**"Cycle" Engine.**—In outward appearance the "Cycle" engine, patent No. 3522, March 12, 1886, seems to differ little from the ordinary type of a compression gas engine. The axis of the horizontal cylinder is placed, accordi[illegible] usu[illegible]

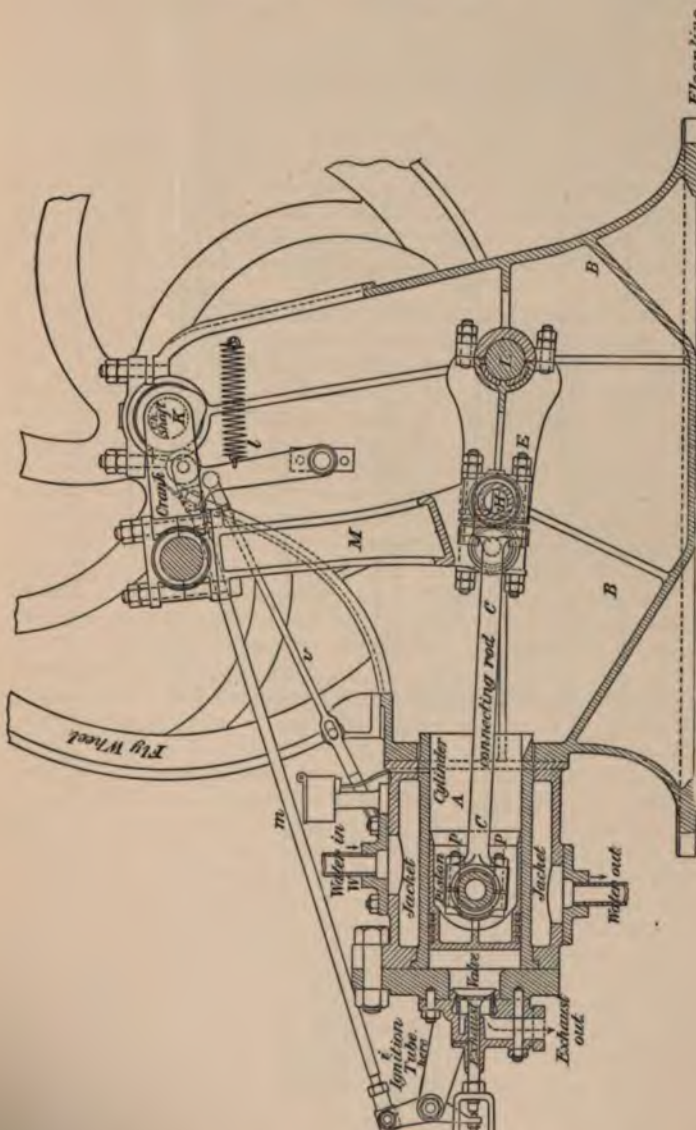


Fig 44.—Atkinson Cycle Engine—Elevation.

angles to the crank shaft, the side next the crank being open, it contains only one piston. Nevertheless, in this, as in

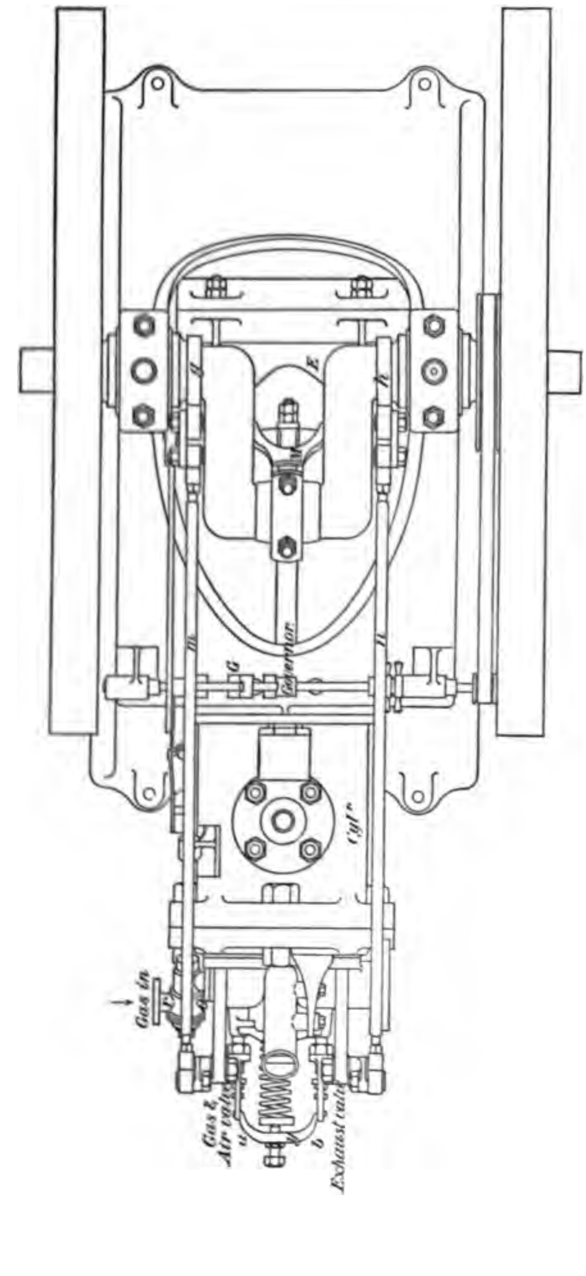


Fig. 45.—Atkinson Cycle Engine—Plan.

the Differential engine, the expansion and exhaust strokes are longer than the admission and compression strokes, and the whole cycle of operations is completed during one revolution of the crank, with one piston and cylinder, without the aid of a pump. This constitutes the novelty of the "Cycle" engine. Instead of using two pistons, the four unequal strokes are all obtained with one piston, working upon the motor crank through a series of rods, links, and levers, instead of acting through the usual connecting-rod. The admission and exhaust are operated with valves in the ordinary way. There is no valve to the ignition tube, but the charge is ignited automatically during the compression stroke.

Fig. 44 gives a sectional elevation, and Fig. 45 a plan of a 2 H.P. "Cycle" engine. A is the cylinder, P the piston, at W the water enters the jacket. The cylinder is placed upon a strong base-plate, B, in the interior of which is the mechanism for transmitting power to the crank. The engine is provided with two flywheels. E is the lever, H the small crank or vibrating link, the end of which only is seen, C is the connecting-rod, M the lever joining H to the crank shaft K, and L the fixed point in the base, about which the lever E and small crank H oscillate. G is the ball governor, acting upon the gas admission valve by a lever, *l*, and valve-rod, *v*, shown in Fig. 44. As long as the speed is regular, the valve *o* opens to admit the gas. The rod *v* rests against the valve, but is not solidly connected, and if the speed be increased it is drawn back, the valve remains closed, and no gas is admitted.

At *a* and *b* are the valves for admitting and discharging the gases, worked by two rods, *m* and *n*, and opened by the two cams, *g* and *h*, on either side of the crank shaft. Except when acted upon by the cams, they are held against the end of the cylinder by a spring and connecting stirrup, *y*, Fig. 45. *r* is the cock for admitting the gas, and *i* the ignition tube, kept at a red heat by a Bunsen burner. The tube *i* is permanently open to the cylinder through a very small passage, and has no timing valve to uncover it at a given moment, and ignite the gases. The ignition of the charge in this engine is based upon the theory, that a small quantity of the gases of combustion always remains in this narrow passage. The pressure of the return stroke drives these gases and a portion of the fresh compressed mixture up the red-hot part of the tube, where they ignite, and spreading back into the cylinder, fire the remainder. The method works well, owing probably to the purity of the charge obtained by the long exhaust stroke, and ignition is perfectly regular. The exact moment of firing is determined by raising or lowering the chimney, and altering the position of the tube, but the time of ignition is not so precisely fixed in this as in most engines. Premature ignition during the exhaust stroke is prevented by

the low pressure of the gases of combustion. But whether ignition occurs at the inner dead point, or when the piston has moved out a little way, does not greatly affect the action of the engine. In the one case the expansion stroke is longer, in the other the pressure is higher.

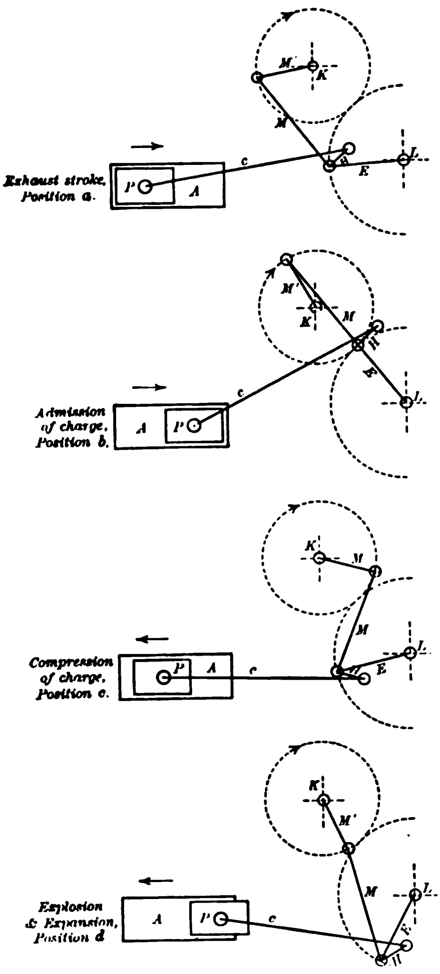


Fig. 46.—Atkinson Cycle Engine—Four positions of Link and Toggle Motion.

In these details the Atkinson engine differs little from others. Its distinguishing feature, by which practically complete expansion is said to be obtained, is the link and toggle motion shown in four positions at Fig. 46. A is the cylinder and P the piston as before. *c* is the connecting-rod to the small vibrating link H, which, through E, is joined to the fixed point L. M is the lever connecting through the crank $M_1$ to the crank shaft K. Position (*a*) shows the end of the exhaust stroke, when the piston is at the inner dead point. The piston moves out, drawing in the charge, and the lever M rises, carrying the link H with it. At (*b*) the crank has performed nearly a quarter of a revolution, and H and M are in their highest positions. The energy of motion carries M and $M_1$ round, forcing down H (position *c*) and the piston moves in, compressing the charge, but not to the t from whence it started. The clearance space left at the of the cylinder is slightly larger than before, and the charge

is driven into it, at a pressure of about 45 lbs. The proportion of compression to admission is as 4 to 5. At the end of this stroke, when the crank has performed another quarter revolution, the pressure forces the gases up the red-hot tube, and ignition follows. The piston is driven out to the extreme limit of the cylinder, M and H are both in their lowest positions (*d*), and the crank has completed three-quarters of a revolution. The exhaust stroke following is longer than the expansion, since the piston moves in to the extreme end of the clearance space. M and H are raised, the crank completes its revolution, the products of combustion are thoroughly discharged, and the cylinder cleared for the next admission-stroke. Fig. 46*a* shows the same

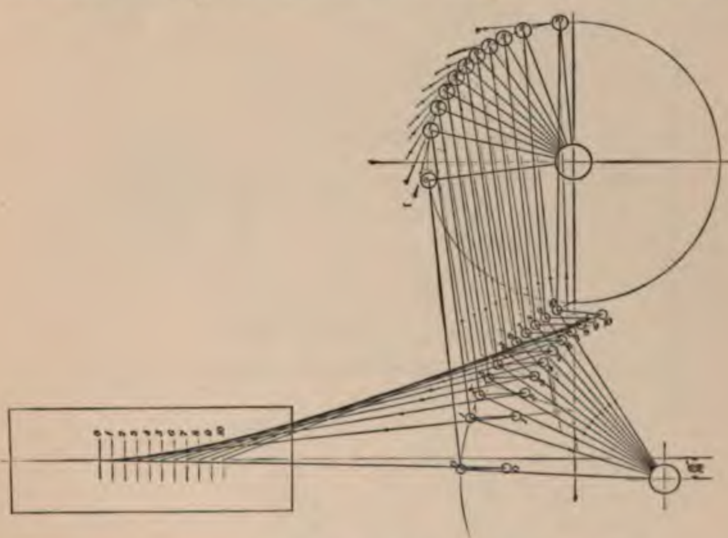

Fig. 46*a*.—Atkinson Cycle Engine—10 Positions of Crank, &c.

arrangement for ten positions of the piston, connecting-rod, lever, and crank during one stroke. In the "Cycle" engine the ratio of the cylinder volume utilised for compression is 2·5, and for expansion, 4·3. The lengths of the four unequal piston strokes are:—First forward stroke (admission), 6·3 inches; first return stroke (compression), 5·03 inches; second forward stroke (expansion), 11·13 inches; second return stroke (exhaust), 12·43 inches. These dimensions are for an engine of 2 H.P. nominal.

The proportion of exp[illegible] to admission and compression can be varied to suit [illegible] of gas. By adjusting the centre L and link [illegible] is easily adapted for Dowson gas. The prolon[illegible] is a source of economy.

The gases are discharged at a pressure of only 10 lbs., and the cylinder being thoroughly cleansed after each explosion, ignition is said to be more certain. The usual strength of the charge is 8 parts of air to 1 of town gas. Sometimes the dilution is 6 to 1, but the mixture is richer than in the Otto engine, as the charge is free from the products of former combustion. Experiments lately made by Mr. Atkinson, to determine the effect on the

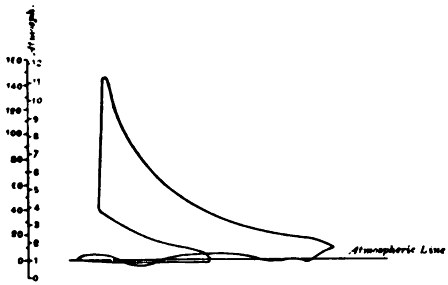


Fig. 47.—Atkinson Cycle Engine—Indicator Diagram.

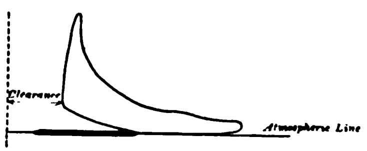


Fig. 48.—Atkinson Differential Engine—Indicator Diagram.

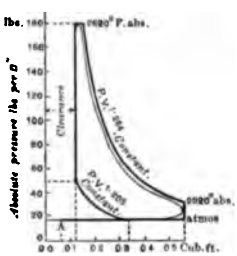

Fig. 49.—Atkinson Cycle Engine —Indicator Diagram.

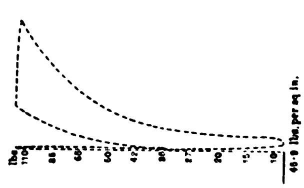

Fig. 50.—Atkinson Cycle Engine —Indicator Diagram.

consumption of gas of wholly driving out, or retaining in the cylinder a portion of the burnt products, gave an economy of 3 cubic feet of gas per B.H.P. per hour when the cylinder was thoroughly cleansed, equal to 11·7 per cent. of the total consumption of gas.

**Trials.**—The trials made on the Atkinson ri· the table at pp. 400, 402, 404. It has been

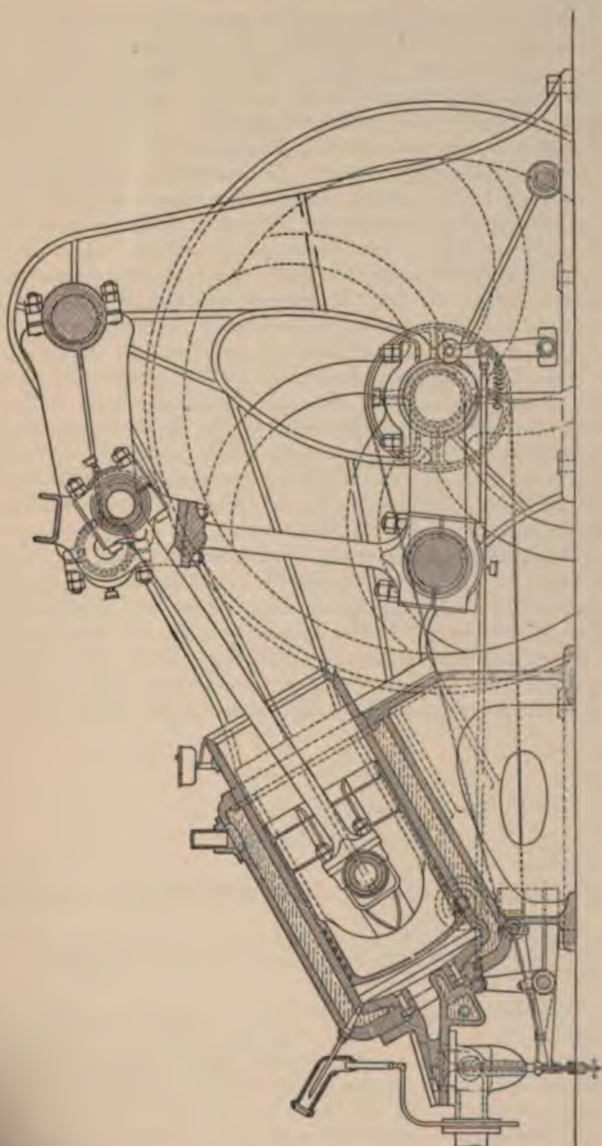

Fig. 51.—Atkinson Cycle Engine—100 H.P. nominal.

fessors Unwin, Schöttler, and Thurston. In an important
made by Professor Unwin in 1887, the diagram of

which is given at Fig. 47, the consumption of London gas in the Atkinson engine was 22·5 cubic feet per B.H.P. per hour, and the ratio of expansion 3¾, as compared with 2½ in the Otto. Professor Schöttler did not obtain such favourable results, but his engine was of the Differential type. Fig. 48 shows a diagram taken during the trial. The Society of Arts' experiments have been already quoted. In these the consumption of gas for the Atkinson engine was 19·22 cubic feet per I.H.P. per hour, the lowest figure recorded for any of the competing engines. A diagram of this trial is given at Fig. 49. One of the most complete tests on the Atkinson engine was made in October, 1891, at the Uxbridge Water Works by Mr. Tomlinson. In this experiment, not only the efficiency of the engine, but the value of the Dowson gas used to drive it, was determined. The engine indicated 21·95 H.P., and the anthracite burnt amounted to 1·06 lb. per I.H.P. per hour. Fig. 50 shows a diagram taken at this trial. The best steam engines require about 2 lbs. of good coal per I.H.P. per hour.

At Fig. 51 is shown a 100 H.P. nominal "Cycle" engine, with the cylinder slightly inclined. The drawing was kindly given to the author by Mr. Atkinson.

The Atkinson engine is made by the British Gas Engine and Engineering Co. A type, surnamed the "Utilité," has lately been introduced, specially for small powers and high speeds. The action of the engine is the same as in the "Cycle," with an impulse every revolution, but the cylinder is horizontal, instead of being inclined. The crank is enclosed, forming a reservoir, into which air is compressed by the action of the piston.

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## CHAPTER IX.

## THE GRIFFIN, BISSCHOP, AND STOCKPORT ENGINES.

CONTENTS.—Griffin Six-Cycle Types—Horizontal and Vertical—Trials—Bisschop—Method of Working—Tests—Stockport—Types.

**The Griffin Gas Engine.**—This horizontal engine, constructed by Messrs. Dick, Kerr & Co., of Kilmarnock, has had considerable success in England, especially where great steadiness and regularity of speed are required for electric lighting, but it is little known abroad. There is only one cylinder and piston. The engine belongs to the six-cycle type, is in a certain double-acting, and both sides of the piston are used for of the charge, as in a steam engine. It is probab motor of this special type which is still made.

At p. 62 will be found a description of the method of operations in a six-cycle engine. There are six strokes of equal length, comprising—1, Admission of charge; 2, compression; 3, explosion and expansion; 4, expelling products of combustion; 5, drawing in air or scavenger charge; 6, expulsion of charge of air. The defects of this cycle are—the want of regularity in the speed, and the loss of power due to the small number of ignitions, there being only one motor stroke in six. These disadvantages are to a certain extent avoided in the Griffin, by making it double-acting. Instead of one ignition and one working impulse every three revolutions, a charge of pure air is admitted, and an ignition obtained, alternately on either side of the piston, at every one and a-half revolutions of the crank, and for every three strokes. Thus the action is much more regular, but the heat generated by the explosions taking place on both sides of the piston is almost as great as in the Lenoir engine. This is partly counteracted by the scavenger charge of air which, by cooling the cylinder, has a beneficial effect on the temperature of the walls. To diminish further the heat of the explosion, there is not only a water jacket to the cylinder barrel, but to the cylinder cover next the crank, through which the piston-rod works. This has a cooling effect on the rod, and the indicator diagrams, taken during the trials of the Society of Arts, showed that the mean pressure in the front end of the cylinder was from 6 to 14 lbs. lower than at the back, where there was no cover jacket. The piston-rod, thus cooled, carries off part of the heat, and reduces the pressure.

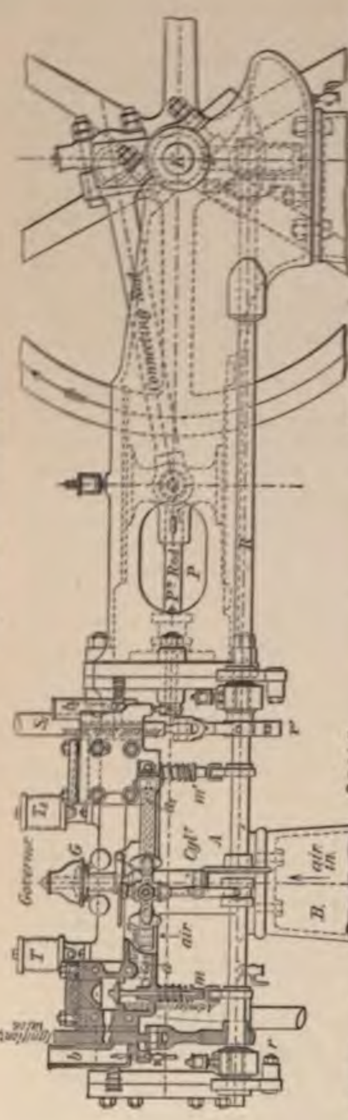
The following table explains the double action of this engine:—

| Front of Piston (crank end)—3 revolutions. | | Back of Piston—3 revolutions. |
|---|---|---|
| Forward stroke—1, Admission of charge of gas and air.<br>Back stroke—2, Compression of charge of gas and air. | 1 rev. | Back stroke—1, Discharge of burnt products through exhaust.<br>Forward stroke—2, Drawing in scavenger charge of pure air. |
| Forward stroke—3, Ignition and expansion of charge of gas and air.<br>Back stroke—4, Discharge of burnt products through exhaust. | 1 rev. | Back stroke—3, Driving out scavenger charge of pure air.<br>Forward stroke—4, Admission of charge of gas and air. |
| Forward stroke—5, Drawing in scavenger charge of pure air.<br>Back stroke—6, Driving out scavenger charge of pure air. | 1 rev. | Back stroke—5, Compression of charge of gas and air.<br>Forward stroke—6, Ignition and expansion of charge of gas and air. |

The strokes forward and back, corresponding in number, as 1 – 1, occur
side of the piston.

r generated is of course expended in
done on the gas by the momentum

Fig. 52.—Griffin Six-Cycle Engine—Side Elevation.



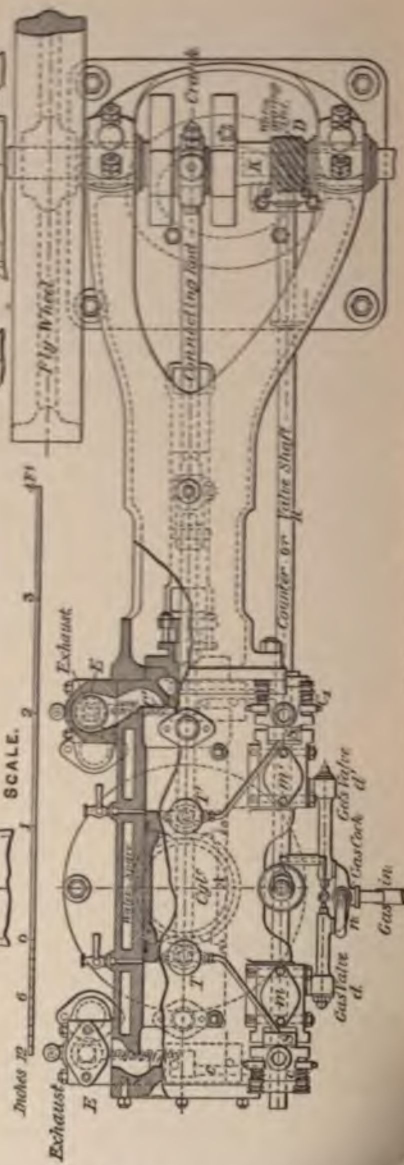




Fig. 53.—Griffin Six-Cycle Engine—Plan.

of the flywheel, &c., instead of positive work of the gas on the engine. Although a six-cycle, by making it double-acting,

becomes virtually what may be called a three-cycle engine. There are two small slide valves driven by the counter shaft, working the admission on each side of the piston. Through them the charge of pure air is also admitted and expelled.

Fig. 52 gives a side elevation, and Fig. 53 a plan of the Griffin engine. Power is transmitted by the connecting-rod to the crank shaft K, and there are usually two flywheels. The counter shaft R is driven from the crank shaft by worm gearing D, in the proportion of 3 to 1. It revolves, therefore, once for every three revolutions of the crank shaft. The cylinder itself, closed at both ends, stands on a base or foot B, through which the air is drawn for the motor and scavenger charges. The slide valves $S\,S_1$ driven by eccentrics from the counter shaft, contain the distributing and ignition ports; the two exhaust valves $E\,E_1$ worked by cams, $c\,c_1$, and levers, are on the opposite side of the cylinder to the slide valves. In Fig. 53 the gas is admitted through two valves, $d$ and $d_1$, controlled by the graduated cock $n$. The air enters at $a\,a_1$, Fig. 52, from the base B, and the two mingle at the admission valves $m\,m_1$. These valves are opened by cams on the counter shaft twice in one revolution, or every one and a-half revolution of the crank shaft; the gas valves $d\,d_1$ open only once every revolution, or once for every three revolutions of the crank shaft. Consequently every other time the valves $m\,m_1$ open, they admit only pure air to form the scavenger charge, and every other time they admit air mixed with gas from the valves $d\,d_1$ to form the explosive charge. The gas admission valves are controlled by the governor G, by means of a cam with steps of varying width; the quantity of gas admitted is first diminished, then totally cut off, on one or both sides of the piston, according to the excess of speed.

The charge of gas and air being thus admitted at either end of the cylinder, the slide valves $S\,S_1$ worked by the eccentrics $r\,r_1$ are alternately raised once in every revolution of the counter shaft, and the fresh mixture is made to communicate through the passages shown in Fig. 52 with the permanent burners $b\,b_1$. The charge is thus fired, and the mixture explodes, driving the piston forward. The exhaust valves at $E\,E_1$, Fig. 53, are worked as in the Otto, by cams, $c\,c_1$, and levers passing beneath the cylinder. These cams on the counter shaft R open the exhaust first at one end, then at the other of the cylinder, every half revolution of the counter shaft. $T\,T_1$ are the oil cups lubricating both sides of the cylinder. The heat and friction, generated by the double action, make it important to lubricate the engine carefully, and the oil mus[t] be pure.

**Griffin Types.**—Thre[e t]ypes of the Griffin are made, all six [illegible] ntal motor here described is the [illegible] with one cylinder. Where it [illegible] piston, an engine may

be constructed of half the area of cylinder, and giving the same power at the same piston speed, as a single-acting motor. Professor Kennedy found, when experimenting on a Griffin engine, that, during a continuous run of six hours, the parts were not unduly heated. He was of opinion that space and power might in this way be economised, but for various reasons the type has not hitherto been generally adopted.

In the twin-cylinder Griffin engine, used for electric lighting, where great regularity of working is required, there are two horizontal cylinders side by side, each single-acting, and having one motor stroke in six. The cranks of the pistons work in the same plane at 180°, and an explosion is obtained every three revolutions from each cylinder, or for every one and a half

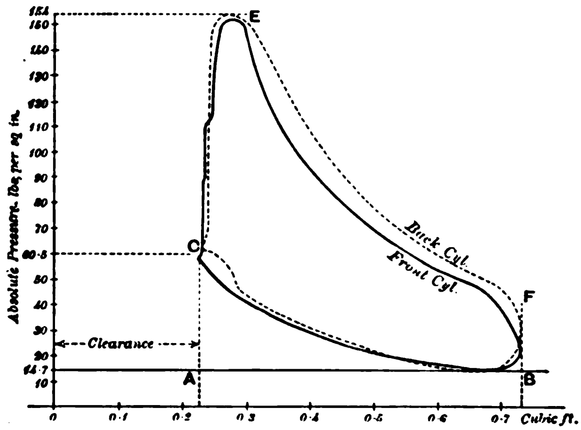



Fig. 54.—Griffin Engine—Indicator Diagram.

revolutions of the crank shaft. The action is similar to that of the double-acting engine, except that the operations, instead of taking place in one cylinder, alternately, on either side of the piston, are carried out in the two cylinders, on one side only of the piston. The whole cycle of operations is gone through in each cylinder, and the charge is admitted, compressed, ignited, expanded, and driven out, and the scavenger charge of air introduced and exhausted. In the one cylinder the cycle is three strokes in advance of the other. The forward motor stroke of one piston corresponds with the expulsion of the scavenger charge of air in the other, and admission in one cylinder with exhaust in the other.

The third type of this engine, for small powers, is vertical. It is single-acting, and hence there is only one explosion and one motor stroke for every three revolutions

crank, or one working stroke in six. Considerable speed is therefore necessary to give the power, and the engine runs at about 200 revolutions per minute. The general construction and the cycle of operations are the same as in the other types, but the parts are not in duplicate, and there is only one gas admission and exhaust valve. This engine is made in sizes up to 6 H.P. nominal, but is little used except for very small powers. It is handy and compact and runs quietly, but not with the same regularity as the double-acting engine. The scavenger charge of air tends to cool the walls, and diminishes the amount of water required for the jacket, and there is less heat to counteract than in four-cycle engines.

Three important trials have been made upon the Griffin engine, the first by Professor Jamieson, the second by Professor Kennedy, F.R.S., both at Kilmarnock, the third at the Society of Arts' trial competitions in 1888. In Professor Kennedy's trial an engine was tested of 14·94 B.H.P. with 23 cubic feet of gas consumed per brake H.P. per hour. The indicator diagram of this trial is shown at Fig. 54. At the trials of the Society of Arts (diagram Fig. 55), the engine indicated 15·47 H.P., and the results were not so favourable. The gas used amounted to 23 cubic feet per I.H.P. and 28 cubic feet per B.H.P. per hour. Part of the increased expenditure of gas was probably due to the rather smaller size of the engine. Most gas motors, other conditions being equal, vary in consumption of gas inversely in proportion to the H.P. developed. It should be remembered that the heating value of London, as compared with Scotch gas, is also much lower, and this affected the results. The Griffin engine at the Society of Arts' trial was especially commended for steadiness of speed and regularity.

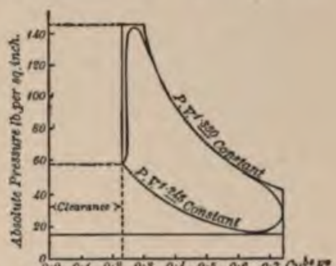


Fig. 55.—Griffin Engine—Indicator Diagram.

**Bisschop.**—The Bisschop engine presents another example of a special type, and cannot be classified under any of the regular divisions of gas motors. Brought out for very small powers by Alexis de Bisschop in 1870-72, it can scarcely be called a modern engine, though ... still made. It appeared about four years after the Otto ... Lange... non-compression atmospheric engine, ... v to avoid the noise and recoil of the ... gear, ... other defects of that ... s ca... type. The charge ... sure, and the force

of the explosion drives up the piston, but it is attached in a special way to the crank, and does not run free. The pressure of the atmosphere, and the energy stored up in the flywheel, then drive down the piston into the vacuum formed below by the cooling of the gases. The action of the walls is here partly turned to good account, reduces the temperature of the exhaust gases, and helps to form the vacuum. In a certain sense the Bisschop, like other atmospheric engines, may be called double-acting, the force of the explosion being used on one side of the piston, and the pressure of the atmosphere on the other. With the exception of a few small French motors, it is probably the only non-compressing engine still in the market. Although originally brought out in France, it has had more success in England, and is practically a British engine. It is said that about 2,000 motors have been sold in this country.

Like all non-compressing engines, the Bisschop is not very economical, and this may be the reason why it is no longer in favour on the Continent, where the high price of gas makes economy in a gas engine of so much importance. Many cases occur, however, where simplicity and ease in starting and in handling are more necessary, and here the Bisschop, which is a most convenient little motor, has been found of use for very small powers. The English makers are Messrs. Andrew of Stockport.

The engine has a vertical cylinder closed at both ends, and the piston-rod works in an upright hollow column. Above is a crosshead from which the connecting-rod, working direct through the crank on to the motor shaft, hangs parallel to the piston-rod during the up stroke. All these parts are close to the high column carrying the piston and rod, and this causes a good deal of vibration, but the impulse from the piston to the crank is direct. Explosion occurs immediately after the piston has passed over the lower dead point. The shock forces up the piston rapidly, the crank is carried round through more than half a revolution, and the connecting-rod brought parallel with the piston-rod inside the column. Thus expansion is exceedingly rapid, and proportionally greater than admission. The distribution of the gas and air, and the discharge of the exhaust gases, are effected by a trunk piston valve, driven from an eccentric on the crank shaft. Gas and air are first admitted through valves covered with thin rubber discs; the air valve is perforated with 18, and the gas valve with 3 holes, admitting the charge in the proportion of 6 parts of air to 1 of gas. The piston valve is then driven down, and brought into line with the distributing chamber, and the corresponding admission port of the cylinder. Cold air is also sometimes admitted into the ports at the beginning of the up stroke, to cool the products of comb

The engine has no water jacket, the cylinder b externally with ribs, to cool the metal. Strang

only works without oiling, but the manufacturers expressly stipulate that neither the piston nor the other parts shall be lubricated. A few drops of oil are applied occasionally to the crosshead and the motor crank only. Ignition is obtained by an external flame.

Fig. 56 gives a sectional elevation of the Bisschop engine, and Fig. 57 a section of the piston valve. The parts are lettered alike in the two drawings; the piston valve admits, distributes, and expels the charge. A is the motor cylinder and P the

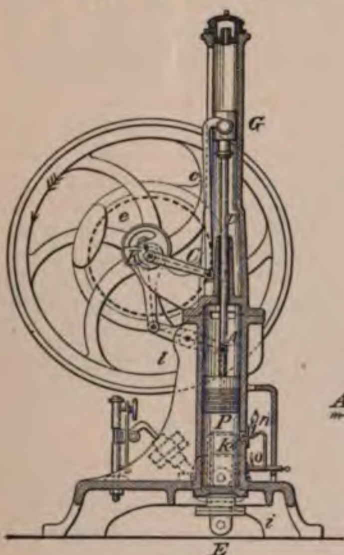



Fig. 56.—Bisschop Engine—Sectional Elevation.

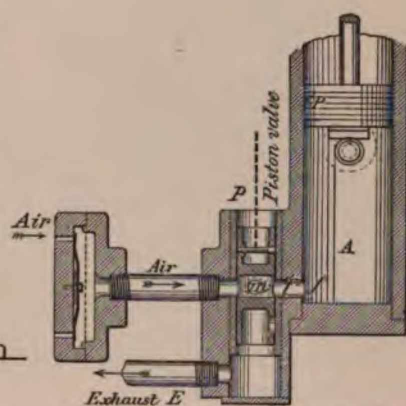



Fig. 57.—Bisschop Engine—Section of Piston Valve.

piston, $c$ is the connecting-rod and C the crank, K the crank shaft. G is the crosshead, and $r$ the piston-rod working in it. In Fig. 56 the piston is half way through the up-stroke. The eccentric $e$ on the crank shaft drives the piston valve $p$ (Fig. 57) through lever $l$. The exhaust is seen at E; $k$ is the small opening about half way up the cylinder, covered by a flap valve; an external flame burns behind it at $n$, and at $o$ is a second auxiliary flame, to rekindle the other when blown out. Fig. 57 shows the air valve with the holes for regulating the supply, and the action of the piston valve $p$; the gas enters at $i$ (Fig. 56).

**Method of Working.**—Beginning with the piston in its lowest position, when the exhaust has just been cut off, the pressure in the cylinder being below atmosphere, gas and air enter

and mix in the distributing chamber. The eccentric drives down the auxiliary piston, and brings its opening m opposite the mixing chamber and the port f into the cylinder. The charge enters while the energy stored up in the flywheel carries the piston past the lower dead point. The opening k is next uncovered, the flap valve hanging loose before it is lifted by the vacuum, the flame is drawn in and the charge fired. Explosion follows, and the pressure closes instantly the admission and ignition valves, until the piston valve, raised by the eccentric, has shut off the distributing chamber. The piston flies up with great velocity, and more energy is generated than can be utilised in the up stroke. The reserve force carries the flywheel through the remainder of its revolution, and drives the piston down. The exhaust valve is next opened, and, during the greater part of the down stroke, the gases of combustion are driven out through the port uncovered by the piston valve, which is now in its highest position. When the pressure in the cylinder is below atmosphere, and a vacuum has been formed, the suction lifts the rubber discs covering the gas and air admission valves, the charge enters, and the cycle is repeated. The exhaust down stroke is slower than the up expansion stroke.

The Bisschop engine has no governor; the regulation of the speed is ingeniously effected by two rubber bags. The larger one acts as a reservoir, and the gas passes from it into the smaller bag, which is so constructed that it receives and passes on to the cylinder exactly as much gas at a time, as is required to keep the engine at any given speed. By checking the quantity of gas, the number of revolutions can be varied. The arrangement of the ignition flame is also modified in different engines, and the second flame is frequently used to heat the cylinder at starting.

**Trials.**—Several experiments have been carried out on the Bischopp engine, all showing a relatively large con-

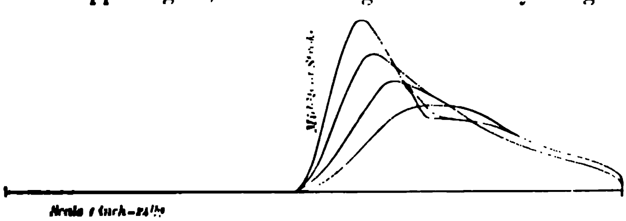



**Fig. 58.**—Bisschop Engine—Indicator Diagram.

sumption of gas. Tests made at the Stockport Exhibition and elsewhere gave a mean of 139 cubic feet of gas per H.P. per hour. An experiment by Meidinger on a larger engine d a consumption of 74 cubic feet of gas per I.H.P. per h gine should not, however, be judged only by its e s.

Neither water nor oil are required for the cylinder, and the motor is often used to replace manual labour. Its advantages disappear when the engine is made for larger powers, although the consumption of gas is proportionately diminished. In England, where it is most employed, it is seldom constructed for more than 1 H.P. Fig. 58 shows a diagram of a 1 man-power Bisschop engine.

**Stockport.**—The Stockport engine, made by the same firm as the Bischopp, Messrs. Andrew & Co., of Stockport, is a four-cycle single-acting motor, in which compression takes place in an auxiliary pump, and an explosion every revolution is obtained. This division of the cycle of operations between two cylinders adds to the size and cost of an engine, but in-

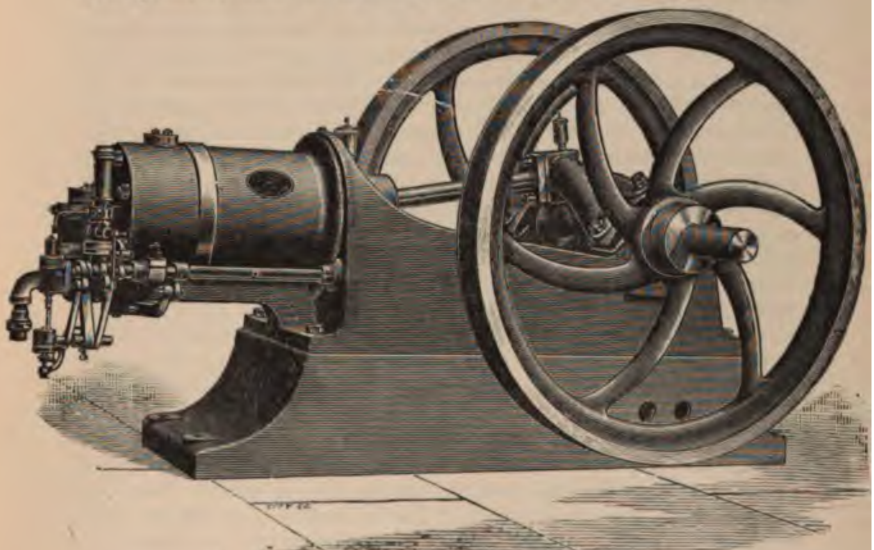


Fig. 59.—The Stockport Engine, latest type.

creases its steadiness of running. In this respect the Stockport resembles the Clerk, as distinguished from the Otto type, and in several working details it is similar to the Tangye, described at p. 68.

There are three types of this engine. In the first, introduced in 1883, two horizontal cylinders, motor and pump, are placed opposite each other, on the same axis, upon a base through which the compressed charge is conveyed from one to the other. Each [illegible] a trunk piston, the main crank shaft is placed between them, the two [illegible]ing-rods work on to it. Formerly the motor [illegible] tv [illegible]ves. On the pump was a vertical valve for [illegible] and passing it on after compression to the

motor cylinder, at the back of which was a horizontal slide valve, carrying the ignition flame in a hollow cavity. The latter valve has now been abolished, and all the Stockport engines are fired by hot tube ignition. There is no exhaust valve. The two pistons move alternately in and out, the forward stroke of the pump piston drawing the charge through the admission slide valve, while the corresponding back stroke of the motor piston uncovers the exhaust port, and drives out the products of combustion. The following back stroke of the pump piston is simultaneous with the forward expansion stroke of the motor, and by it the charge is compressed, through the same slide valve, into a hollow chamber in the base-plate. At the conclusion of this stroke, when the pump piston has reached its inner dead point, the pressure opens a valve into the working cylinder at the moment when, the motor piston having passed its outer dead point, the exhaust port is uncovered. The high pressure of the incoming charge helps to drive out the gases of combustion, but it is difficult to avoid the escape, with them, of a certain quantity of the fresh unburnt charge. The return stroke of the motor piston closes the exhaust port immediately after, and further compresses the charge, together with the products of combustion left in the cylinder, after the rapid closing of the exhaust. Ignition follows, the timing valve of the hot tube being lifted by the pressure of the charge, and the cycle recommences. Thus admission and compression take place in the pump, while expansion and discharge of the products of combustion are carried out in the motor cylinder, the piston of which completes the compression of the charge at the end of the back stroke.

With the exception of the additional pump, the parts of this engine are few and simple. The one vertical slide valve for admission and distribution of the charge is driven from an eccentric on the crank shaft. The mixture is admitted and compressed in the comparatively cool pump, and is, therefore, not heated by contact with the walls of the explosion cylinder. The slide valve also is more durable, because it is not exposed to great heat. Construction is further simplified by the absence of an exhaust valve. This is considered by the makers an advantage, as these valves are apt to become clogged with carbon, but it is probably in part counterbalanced by the waste due to the almost simultaneous admission of the fresh, and driving out of the former charge. The exhaust ports in the Stockport are disposed with great care. In all gas engines they should have an outlet as direct as possible into the air, and not pass into drains or chimneys, and all sharp bends should be avoided. It is wise to make provision for cleaning out these ports and pipes, and most makers have now introduced some special apparatus to diminish the noise of the exhaust.

The hot tube ignition is another feature of the Stockport engine. Formerly these tubes were always made of cast iron, and lasted only about thirty hours. Under ordinary conditions, they are rapidly burnt out by the great heat to which they are subjected, and the quick variations of temperature produce great changes and deterioration in the metal. The fresh compressed charge entering the tube at each stroke is always at a high temperature, while the residuum of exhaust gases left in it during the out stroke is relatively cooler, and, through these alternations of heat, the tube is speedily burnt away. In the Atkinson and other engines a high chimney is placed round the tube, to protect it from currents of air. Messrs. Andrew have introduced a special composition, made of an alloy of silver, &c., and they maintain that it does not fuse or cake, and lasts for several months, if the tube be protected by a chimney. Ignition tubes have the advantage of being easily removed and changed when worn out, and are almost universally used in England. They are simple and regular in action, but their temperature is lower than that of the electric spark, and ignition is more difficult, especially if the mixture is highly diluted. For this and other reasons, the charge is generally fired by electricity in France, where hot tube ignition is seldom employed.

The three types of the Stockport engine all exhibit, under different forms, the same principle of compression of the charge in a separate cylinder. In the second, or double-acting type, frequently made for larger powers, there are two motor and two pump cylinders. The two horizontal motor pistons work on to the single crank placed between them. The smaller pumps are immediately below, and cast in one piece with the motor cylinders, and work on to a second smaller crank on the main shaft, revolving slightly in advance of the first crank. An impulse is obtained at every half revolution, and the engine runs with great steadiness. If less power be required for a time, one pair of cylinders (motor and pump) on one side can be uncoupled, and the engine worked single-acting with the other pair only. The governor is sensitive, and the supply of gas is wholly cut off, as soon as the speed exceeds the ordinary limits. For large powers this engine is sometimes made with four motor and pump cylinders, each giving an impulse every revolution.

The third type of the Stockport engine is constructed for very small powers. It is vertical, and has one cylinder, but the same principle of separate compression of the charge is carried out. As in the Seraing [illegible], a differential piston is used. The lower side of the [illegible] smaller in [illegible]ter, and here the charge is expanded [illegible]ven out; [illegible] upper side, with larger diameter, [illegible] is admitted [illegible] compressed. The piston virtually [illegible] one cyl[illegible] into two parts of unequal area, [illegible] different [illegible] operations take

place simultaneously. During the down stroke the charge is drawn into the upper part, where, the area of the cylinder being smaller, the ratio of admission of the charge is proportionally reduced. The next up stroke compresses the mixture on the upper side of the piston, driving it into an annular space, from whence it passes into the lower part of the cylinder. The following down stroke, after discharging the exhaust gases, completes the compression of the charge on the lower side of the piston. Here ignition by the hot tube and expansion take place, and the volume of the cylinder being larger, expansion is greater in proportion to admission. This little engine is simple in construction. It has no slide valve; the governor is of the weight type vibrating round a spindle, easily adjusted by a screw to suit any speed.

As soon as the Otto patent expired, the Stockport firm, among others, adopted the Otto type without a pump for one class of engine, using their own valves and patent ignition tube, as shown in Fig. 59, p. 117.

## CHAPTER X.

## OTHER BRITISH GAS ENGINES.

CONTENTS.—Electric Lighting—Tangye—Fawcett—Acmé—Fielding—Forward—Midland—Express—Dougill—Trent—Shipley—Trusty—National—Palatine—Robey—Day—Campbell.

Two circumstances have chiefly contributed to the great development of gas engines within the last few years in England. The first is the extensive and increasing application of electricity to lighting, and the demand which has arisen for gas engines to drive the dynamos in country mansions, &c., as more suitable and economical than steam. No cost is incurred with gas engines when not running. As it is seldom necessary to furnish the power for electric lights for more than a few hours at a time, a gas motor, easily started and stopped, is better than a steam engine and boiler, where the fire must be lighted to get up steam. The economy of gas engines for electric installations is also marked, even where town gas is used to drive the engines. It has been found, and attention was first drawn to the fact by Sir W. Siemens, that coal gas gives much more light when furnishing power electrically through a gas engine and dynamo, than when the same quantity of gas is burnt in the ordinary way. At Dessau in Germany, an electric light installation has been driven by engines worked with town gas since 1886. There are now at this town one engine of 60 B.H.P., and one of 120 B.H.P.,

the latter is coupled direct to its dynamo. This arrangement is found to conduce, not only to increased power, there being less loss in transmission, but to economy of space, when an electric installation is required in the centre of a town. The larger gas engine showed a consumption of 39 cubic feet of town gas per kilowatt, but it is hoped with a better engine that the consumption will be reduced to 30 cubic feet of gas per kilowatt, and 17 cubic feet per B.H.P. per hour. Where gas generators are used supplying Dowson gas to the engines, the economy is much greater, the fuel to generate the gas costing about half that required in a steam engine and boiler, to give the same power. At Schwabing, near Munich, electricity for lighting the town is obtained from an Otto 40 B.H.P. engine, worked with Dowson gas, made from German anthracite coal. The consumption of fuel is 1·54 lbs. per B.H.P. per hour, and 3·3 lbs. per kilowatt per hour. At Morecambe, where three Stockport engines, each of 16 H.P. nominal, are employed to drive the electric light installation, the cost, when town gas was used, was about $1\frac{1}{2}$d. per kilowatt; with Dowson gas it is $\frac{1}{2}$d. per kilowatt.*

Another reason why gas engines have become more popular in England is the expiration of the Otto patent, which has given an additional impetus to their manufacture. Hitherto the four-cycle has been found the best and simplest type of engine, working practically with as much economy as others of more elaborate construction. To avoid infringing the patent, makers had recourse to various devices to alter the working method, most of which were abandoned as soon as the Otto engine became public property. At the same time, the sudden and universal competition reduced the price of gas engines, and increased their sale. Some makers had long been prepared, as soon as the patent expired, to bring out engines using the Beau de Rochas cycle.

**Tangye.**—Among the foremost were Messrs. Tangye, of Birmingham, who ceased to construct the engine described at p. 68 (Robson's patent), and since June, 1891, make engines only on the Otto principle, with Pinkney's improvements. Next to Messrs. Crossley, they at present build some of the largest sized engines in England. Their single-cylinder engines range from $\frac{1}{4}$ to 146 B.H.P., and two cylinder engines from 86 to 292 B.H.P. with town gas (340 I.H.P.) The principal improvements introduced are in the combustion chamber, which is carefully constructed to prevent shock, and render the engine suitable for driving a dynamo direct, and also to ensure steady and complete combustion of the charge, during the whole of the motor stroke. The pressure, as shown by the indicator diagrams,

* These figures are taken from Mr. Dowson's Paper on "Gas Power for Electric Lighting," *Proc. Inst. Civil Engs.*, vol. cxi., 1892-93.

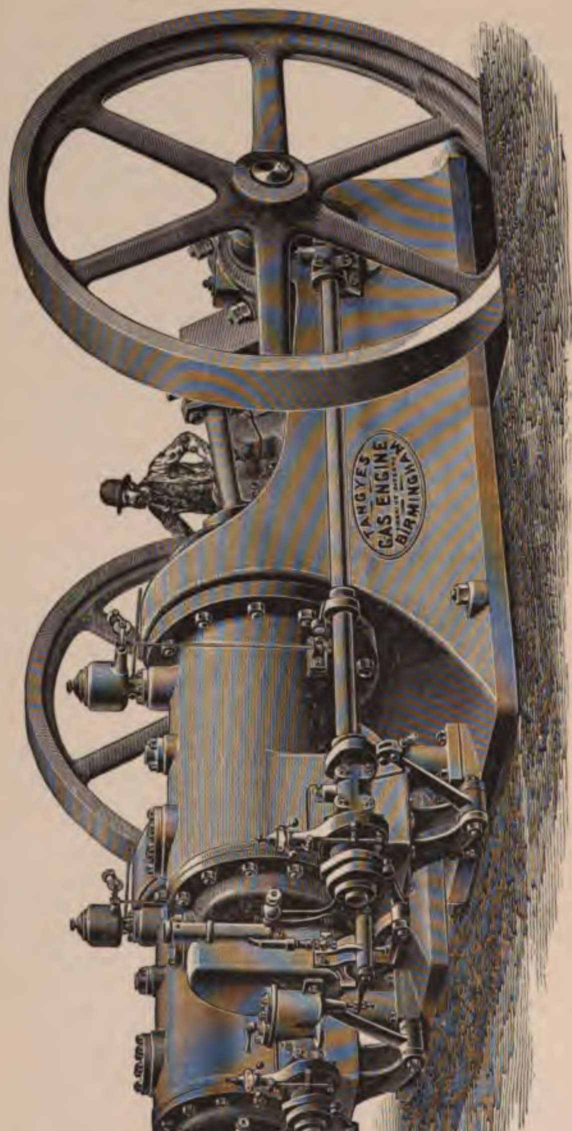



Fig. 59a.—Tangye's Twin-cylinder Gas Engine.

is not so high in the Tangye as in the Otto engine, but it is better maintained, and expansion is more complete. Messrs. Tangye also supply a pressure starter to engines above 16 H.P. nominal, which is said to be able to start even large twin-cylinder engines. A very sensitive governor is also used, and conduces to steadiness in running. A 13 I.H.P. Tangye engine was exhibited at the Royal Agricultural Show at Doncaster in 1891. It was fitted with an inertia governor, consisting of a weight carried round on a coil spring, which opens or misses the gas admission valve, according to the speed of the engine. Under normal conditions, the weight fits at each revolution into a groove on one arm of a lever moving at half the speed of the crank shaft, the other arm of which opens the gas admission valve. But if the speed be increased, the inertia of the weight causes it to be left behind, and to overrun the groove, and the gas admission valve remains closed.

According to the makers, the consumption of town gas in these engines varies from 16 cubic feet per I.H.P. per hour in the large, to 25 cubic feet per I.H.P. per hour in the smallest sizes, but these figures have not yet been confirmed by independent tests. The engines run from 160 to 200 revolutions per minute. Fig. 59*a* shows a view of a coupled twin-cylinder Tangye engine of 200 I.H.P.

**Fawcett.**—The Fawcett engine, made by Fawcett, Preston & Co., Liverpool, resembles the Clerk in principle, having two cylinders, motor and pump, but differs from it in a few important particulars. It is constructed from the designs of Mr. Beechey, who has taken out several patents. In the earliest, No. 4270, dated October 20, 1880, there are two cylinders and two pistons for the motor (expansion) and compression strokes. In a later patent, March 18, 1882, the cycle is accomplished in one cylinder. The engine patented June 30, 1890, has achieved considerable success. It consists of a horizontal motor cylinder, a compression pump below it, working at a different angle on to the crank shaft, and an equilibrating horizontal piston valve at the side of the motor cylinder, driven by an eccentric from the crank shaft. This equilibrating piston valve acts in the same way as a slide valve, and the makers assert that it is simple and well balanced, and that the pressure during explosion and compression is equally exerted over its whole surface. It consists of two piston valves, joined by a short rod, and working in a casing, which communicate with the motor and pump cylinders, and with the ignition tube. In most engines they are surrounded with a water jacket, as shown in Fig. 61. The opening between the pistons forms the channel of communication, and is brought successively to face ports in the two clyinders, and the ignition tube. The construction and working of this valve have been patented.

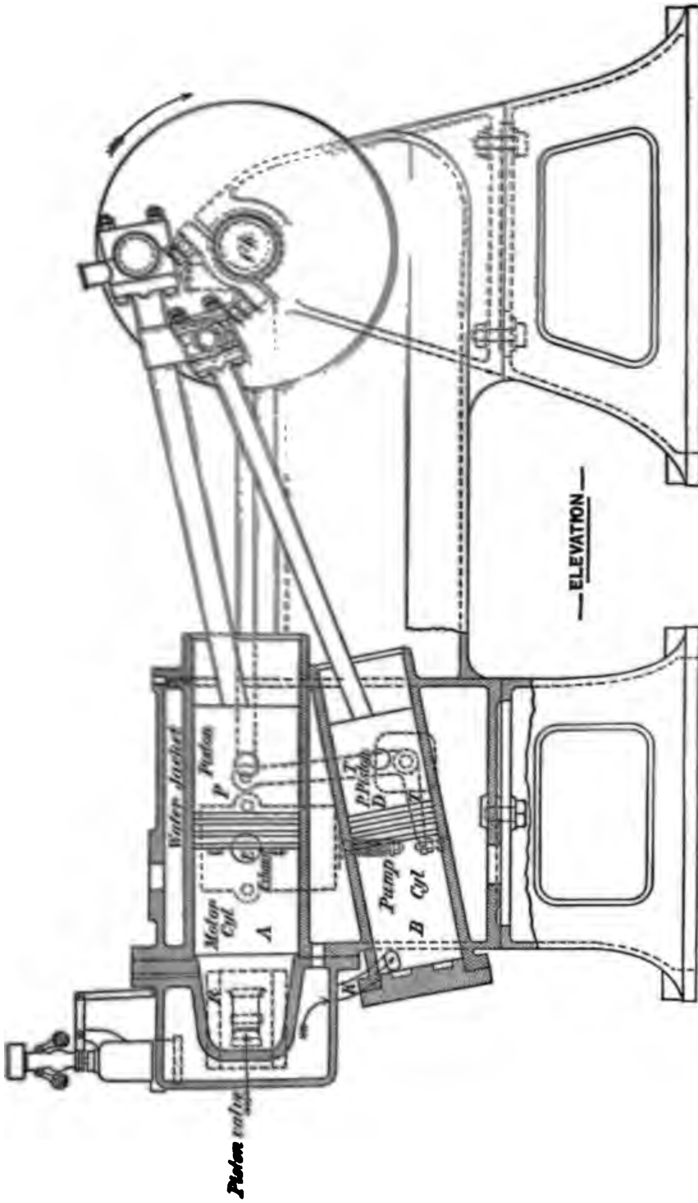



Fig. 60.—Fawcett Gas Engine—Sectional Elevation.

Figs. 60 and 61 show a sectional elevation of this engine, and a plan of the valves. A is the motor cylinder with piston P, B the pump with piston D, R the combustion chamber at the back of the motor cylinder, K the pipe connecting the two cylinders. At E is the exhaust opened by levers T, just before the motor piston completes its expansion stroke. The piston D of the pump being set slightly in advance of the motor, begins the out stroke a little before it, and at the same moment the valve

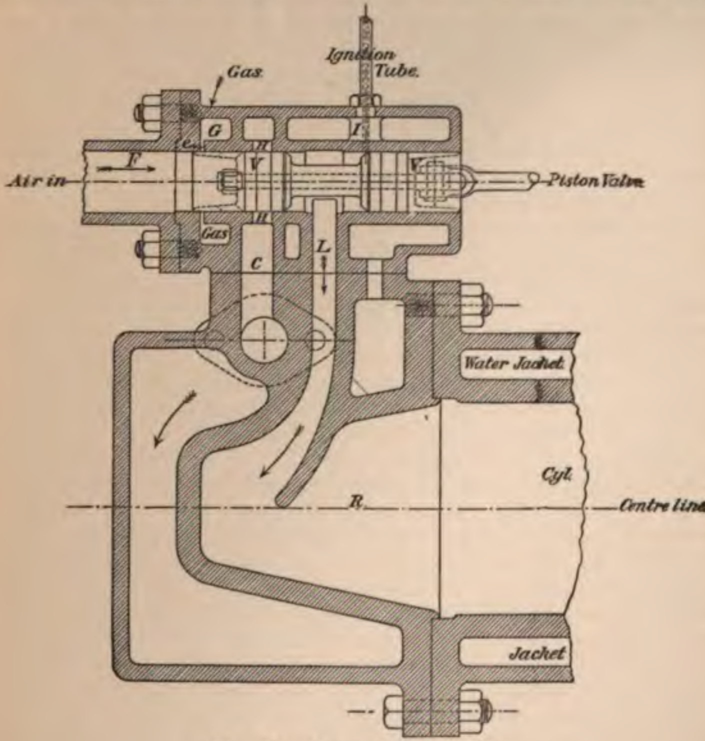



Fig. 61.—Fawcett—Valves, &c.

piston V also moves out. Air enters at F, and gas at G, and mingle at *e*. The forward movement of the valve piston and the out stroke of D, next draw the charge through the ports H H, the pipe C, and the channel K (Fig. 60) into the pump B. On the return stroke of D and the valve piston, the compressed gases are forced back through K and the same ports into the channel formed by the rod between the two valves. From hence they pass through passage L into R, at the back of the motor cylinder, while P is completing its out

stroke. The exhaust is now opened by levers T, the motor piston beginning the return stroke, drives out the gases of combustion, and the compressed charge entering from the pump through the piston valve, assists to expel them. The return movement of P closes the exhaust. Communication between the two cylinders is kept open by the valve, while the air and gas admission are held closed, and both pistons compress the charge into the combustion chamber R. The pump piston completes the in stroke first, and the ports of communication between the two cylinders are closed by the movement of the valve. While the motor still further compresses the charge, the pump and valve pistons begin their out stroke, and the passage in the valve is brought to face the cylinder port L and the ignition tube I. The gases are ignited, and drive out the motor piston, doing useful work. A fresh charge has already been admitted behind D, through the ports of the valve, and the cycle recommences.

Experiments were carried out at Liverpool on a 6 H.P. nominal Fawcett engine by Mr. T. L. Miller, in February, 1890. The heating value of Liverpool gas was found to be rather high. The number of revolutions was 150·8 per minute, the engine indicated 11·49 H.P., and 8·52 B.H.P. The mean consumption of gas was 18·4 cubic feet per I.H.P. per hour, and 24·74 cubic feet per B.H.P. per hour, excluding the gas used to heat the ignition tube. The mechanical efficiency was rather low, viz., 74 per cent. See Table of Trials, p. 402.

**Acmé.**—The Acmé engine, patented by Messrs. Alexander, Burt & Co., of Glasgow, who were formerly makers of the Ajax, shows a novel attempt to solve the problem, how to increase expansion of the explosive gases in proportion to admission and compression. In this engine there are two horizontal cylinders, two pistons, and two crank shafts connected by spur wheels in the proportion of two to one. The cylinders are alongside each other, and the one is shorter and smaller than the other. While the piston of the larger cylinder makes one stroke, the piston of the smaller makes two, one crank and shaft run, therefore, at half as many revolutions as the other. The cylinder volumes and lengths of stroke also differ, and the cranks being at different angles, the pistons do not work together. When the first or larger piston has completed the in or the out stroke, the smaller second piston is about 45° behind. The expansion obtained by using two cylinders and pistons is said to be so complete that the gases, when discharged, are comparatively cool, and the exhaust noiseless. The cycle of operations is divided between the two cylinders. Hot tube ignition without a timing valve, ·d discharge of the gases of combustion, both take place in the ller cylinder, the piston of which uncovers these openings · the beginning and end of its out stroke. The firing of the

charge and the exhaust are timed to occur when the first piston is at positions corresponding to the inner and outer dead points. In other respects the engine presents no new features. There are two flywheels, one automatic lift valve admits the gas and air, and the rod opening it is connected to a pendulum weight governor. An Acmé engine was shown at the Crystal Palace Electrical Exhibition (1892), and was somewhat noisy in action.

Beginning with the exhaust in both cylinders, the following is the cycle of operations. The first piston being at its inner dead point, the first cylinder is completely cleared of the products of the former charge, which are passing out through the exhaust port in the second cylinder. Meanwhile the second piston has begun its return stroke, and discharged the unburnt gases through the exhaust ports uncovered during the out stroke. As soon as the first piston is completely in, the second piston returning, and the volume in both cylinders proportionally reduced, admission commences. The first piston draws in a fresh charge, which is at the same time compressed by the slower in stroke of the second piston, as it passes the dead point. When the first piston is fully, and the second partly out, admission is complete. The first piston then moves in, compressing the charge; the second piston also compresses till the ignition port is reached, and explosion follows. At the moment when the charge is fired, the gases are compressed into little more than the clearance spaces. The explosion drives out both pistons, the first to its farthest limit, the second through part of its stroke, till it reaches and uncovers the exhaust ports. Thus the largest volume in both cylinders is utilised for the expansion stroke. The first piston makes the in stroke, the second completes the out stroke and returns in, covering the exhaust port, and the cycle is repeated.

Several sizes of the Acmé engine were tested, both with full load on and running light, by Professor W. T. Rowden, of Anderson's College, Glasgow. In 1888 and 1889 he experimented upon engines of 2 H.P. nominal, running at 170 revolutions per minute. In the first engine the B.H.P. was 3·16 and the consumption of gas 24·4 cubic feet per B.H.P. per hour. In the later and improved engine, a trial made with full power gave 3·14 B.H.P., and a corresponding consumption of 18·1 cubic feet of gas per hour. Professor Rowden made experiments in December, 1890, on a larger engine of 6 H.P. nominal, where the B.H.P. was 8·28, and gas consumption 17·3 cubic feet per B.H.P. per hour. In a further trial of the same engine the B.H.P. was 7·8, and the gas consumption as low as 16·83 cubic feet per B.H.P. per hour. These trials compare favourably with the standard gas engine trials of the Society of Arts, and the value of the results is enhanced by the fact that the engines tested were not especially adapted to the purposes of the trial,

but ran under ordinary working conditions. Allowance must be made for the richer quality of Glasgow as compared with London gas; 9 cubic feet of the first is computed to give the same heating power as 10 cubic feet of the second.

**Fielding.**—The Fielding engine, made by Messrs. Fielding and Platt, of Gloucester, is constructed on the principles of the Otto, and has the same cycle; the slide valve gear is abolished, and the parts are simple. There is hot tube ignition, but no timing valve. A timing valve is constructed to open the port leading to the hot ignition tube, at the exact moment when an explosion is required. Punctual ignition is a necessary feature of all gas engine cycles. Some inventors, however, have succeeded in dispensing with the timing valve, and they maintain that, by varying the length of the ignition tube, and the distance from the red-hot metal to the motor cylinder, accurate ignition can be obtained. The gases do not reach this heated part of the tube until the end of the in stroke, when compression is greatest. Ignition at the dead point has been one of the main features of the gas engine theory since the time of Beau de Rochas, and it may be doubted whether it is really so easily obtained as these inventors assert. The practice of dispensing with the timing valve is sanctioned by no less an authority than Mr. Atkinson.

In the Fielding and Platt engine the organs of distribution and exhaust, and the oiling apparatus, are driven, as in the Otto, from a side shaft worked by worm gear from the main shaft. The valves are opened by cams. Another cam actuates the governor, which is simply a small dash pot, with a piston connected to a lever opening the gas valve. If the speed be too great, the dash pot cannot overtake the motion of the engine, and is left behind; it drags back the piston, raises the lever, and the gas valve remains closed. Several large sizes of this engine were exhibited at the Royal Agricultural Society's show at Doncaster in 1891, when it was brought to public notice for the first time. The makers claim a gas consumption of 17 to 25 cubic feet per I.H.P. per hour, according to the size of the engine, and quality of gas used. A small vertical 1 H.P. type, resembling the Otto domestic motor, has been introduced by this firm for household use.

A well designed horizontal type of motor indicating 100 H.P. has also lately been brought out. There is one "mitre-seated valve" for admitting the charge, and expelling the burnt products. A piston valve, driven by an eccentric on the crank shaft, opens communication between the inlet and exhaust cylinder ports and this valve, the rod of which is worked by a cam. Ignition is by hot tube, and there is in this engine a timing valve, acted on by the same eccentric as the piston valve. All these organs are contained in a valve chest at the side of the motor cylinder.

This engine is also provided with a special starting gear, consisting of a reservoir, into which air is compressed by the action of the piston. To start the engine the cylinder is first filled with gas, and the supply cocks being closed, the compressed air is then allowed to enter. This method is said to be powerful enough to start an engine with partial load on. The engine has a ball governor, and runs at 160 revolutions per minute. It is illustrated in *Engineering*, January 27, 1893.

**Forward.**—The Forward gas engine, made by Messrs. Barker & Co., of Birmingham, in sizes from $\frac{3}{4}$ H.P. to 50 H.P. is really a "simplified Otto." The Beau de Rochas cycle is used, but several improvements are added. There is no admission slide valve, and ignition is by a hot tube, as in most modern English gas engines. The chief novelty is the device used to obtain punctual ignition of the charge, without a timing valve. The opening of the ignition tube is covered by a rotating disc, with "hit and miss" slots; the surface of the disc is divided into radiating sections, alternately pierced and solid, which, as the disc revolves, are brought successively across the ignition port. According to the section of the disc facing it, the ignition port communicates with, or is shut off from, the cylinder. This arrangement is found in several foreign engines, and is not altogether new. In some of the Forward engines a ball governor, in others a momentum governor, is used. The governing gear is arranged to regulate the speed of the engine in three different ways. It controls the admission of the charge of gas and air into the combustion chamber, and at the same time the rotatory motion of the disc. Unless there is a charge in the chamber, the disc cannot open the ignition port, nor can the charge pass into the chamber, unless an open slot faces the ignition port. Lastly, the governor acts upon the supply of gas, and cuts it off altogether, should the speed increase greatly beyond the normal limits. The same cylinder port serves for the admission of the charge and the exhaust. By this arrangement the port is said to be kept cool, and the waste of mixed gases prevented. The rotating disc is found far less liable to become heated than a slide valve.

Careful tests have been made on the Forward engine by Professor Robert Smith, of Mason College, Birmingham, and by Mr. Holroyd-Smith. Both these experts have reported favourably, pronouncing it a good engine, with all the advantages and few of the defects of the Otto. During trials of several hours' duration, the engine ran very steadily, and was found to work well, even under the severe test of counting the number of revolutions every ten seconds, instead of every minute, and varying the weight on the brake as rapidly as possible. The real test of regular working in an engine is absence of fluctuations in the speed, when the load is suddenly put on or taken off, as in electric installations. In a test made by Professor R. Smith

with full working load, the speed was 176·86 revolutions per minute, and the explosions 59 or 1 for every 3 revolutions. In another at half load the number of revolutions was 177, with 57·8 explosions per minute, or 3·06 revolutions per explosion. The consumption of gas per I.H.P. per hour was slightly less than in the Otto engine. In the first trial it was 20·79 cubic feet of Birmingham gas per I.H.P. per hour, and 23·97 per B.H.P. per hour. Nearly all the tests made under ordinary working conditions give a little over 20 cubic feet of gas per I.H.P. per hour, or about the same as the Otto. The mechanical efficiency of the engine was 86 per cent., and it was timed to run up to 210 revolutions per minute. See Table of Trials, p. 402.

Of the numerous gas motors lately brought out in England, many are made almost exclusively for small powers. These little engines do not vary much in type; their main recommendation is not so much economy of gas, but lightness and simplicity, and the ease with which they are started and worked. In many industrial operations, the use of small gas motors often makes the difference between a profit or a loss to the employer, particularly with the difficulties of modern labour.

**Midland.**—It is a peculiarity of the Midland engine, manufactured by Messrs. John Taylor of Nottingham, that, although especially intended for small powers and domestic purposes, it has two cylinders, motor and pump. Both are single acting, fixed on the same frame, and occupy little more space than the single cylinder of the ordinary type, and all the other parts are simple. The smaller sizes are vertical, the larger engines up to 9 H.P. are horizontal, and adapted for driving with Dowson gas. In the vertical engines the two cylinders are placed side by side, and the pistons work on the same main shaft, by means of two connecting-rods and two cranks. In the pump the charge is admitted and compressed, in the motor it is exploded, expanded, and discharged, and thus an explosion every revolution is obtained. As the crank of the motor piston is set at a different angle to that of the pump, compression is ended, and the charge begins to enter, and to drive out before it the products of combustion in the working cylinder, before the motor piston has quite completed the down stroke. There are no slide valves, cams, or cog wheels, and no counter shaft is necessary, as there is an explosion every revolution. The admission valves are driven by a single eccentric and rod on the crank shaft, and opened once in every revolution, and the gas valve is acted upon by a centrifugal governor, and lifted or closed according to the speed. Ignition is by a hot tube heated by a Bunsen burner, and there is no timing valve; the length of the tube determi[illegible] moment of ignition. The upper portion alone [illegible] heat. The compressed gases are driven into [illegible]

the tube by the down stroke of the compressing piston, and ignite only when the maximum pressure is reached, and they are forced into the upper part. There is no exhaust valve; the gases are discharged silently through a chamber in the base. The gas consumption is small, and the engine requires little lubrication or attention, because the parts are few and simple. Owing to the two cylinders and the explosions obtained every revolution, it is said to give more power for the same expenditure of gas than any other of equal size. A later single-cylinder horizontal type has been introduced, in which the admission of the charge is effected by a rod and lever, and a small crank worked from the main shaft by worm gearing. The exhaust is driven by an eccentric on the same shaft. The supply of gas is regulated by a patent gas bag, and is controlled by an inertia governor. A drawing is given in *The Engineering Review*, August 5, 1891.

**Express.**—The Express, made by Messrs. Furnival & Co., of Reddish, near Stockport, is another single cylinder gas engine which has appeared since the expiration of the Otto patent. In design, construction, and cycle of operations, it closely resembles that engine. Admission is by ordinary lift valves, and hot tube ignition is used. The side shaft is driven in the usual way by worm gear from the main shaft, and a centrifugal governor acts on the gas valve. The engine is made in sizes up to about 9 H.P.

**Dougill.**—The Dougill is a single-cylinder horizontal engine, using the four-cycle, and made by Messrs. Hindle & Norton, of Oldham, in sizes up to 5 H.P. The larger sizes only have a water jacket; in the smaller, the outer surface of the cylinder is provided with ribs, to carry off the heat. The engine is simple and has no slide or ignition timing valve; admission is through mushroom seated valves, worked by cams and levers from the crank shaft. Two novelties are described in the specification. The inventor claims so to time the lifting of the gas and air admission valves, that air only is admitted at the beginning and end, and gas and air in proper proportions during the middle of the admission stroke. According to Mr. Dougill's theory, the residuum of unburnt gases already in the cylinder combines with the air, and forms a cool, non-combustible "envelope" round the rich charge. He endeavours to add to this effect, and to increase the force of the explosion, by injecting the gas through a small pipe into the centre of the cylinder. He maintains that only the inflammable charge in the middle ignites, the surrounding gases do not burn, but take up the heat of explosion in expansion, and help to drive the piston forward, doing useful . Thus the greater part of the heat is said to be utilised, of being carried off by the water jacket. It is doubtful gases are really stratified, and preserve the position inventor. The ignition tube is at the side of

the cylinder, and the upper portion alone is at a red heat. A small side chamber, the size of which is determined by a movable plug, regulates the pressure of the gases. This chamber is the second novel feature in the engine. The mouth of the hot tube is always open, but the final pressure at the end of the return stroke is required, to drive the gases into the glowing upper portion. Gas from the pipe is admitted to the tube at a lower pressure when starting the engine.

**Trent.**—In the Trent horizontal engine, made by the Company of that name at Nottingham, the cycle of operations differs from the Otto in several respects. An impulse is obtained at every revolution by means of a differential piston, several varieties of which have been already described. The use of this compound piston always renders an auxiliary chamber necessary, which in this motor serves for explosion as well as compression. There is no slide valve, and the valves are of the ordinary lift type. Although externally not differing from other gas engines, the motor is really compound, and consists of two cylinders tandem, both water jacketed. There are two pistons of slightly different diameters; both work on to the same connecting-rod and crank. When fully in, the pistons fit the cylinders exactly, but as they move out an annular space is uncovered in the larger cylinder, as the smaller piston passes before it. Into this annular space the charge is first drawn. The valve admitting the gas and air, worked from an eccentric on the main shaft, is raised as the pistons are driven forward by the force of the explosion. The return stroke closes the admission valve, and compresses the gas and air through another valve into the explosion chamber at the side of the smaller cylinder, in which is the hot ignition tube. The compressed charge drives out gases left from the previous combustion through the exhaust lift valve, which is worked by cams from a side shaft in the usual way. The ignition tube is at the mouth of the explosion chamber, at the crank end of the cylinders, and as soon as the exhaust gases have been driven out, and the pressure of the charge is at its maximum, a small valve opening into the tube is raised. The charge is fired, fills the explosion chamber, and enters the motor cylinder at the back of the smaller piston. Both pistons are driven out, a fresh charge is drawn into the annular space, and again compressed into the explosion chamber.

In this engine ignition is effected at constant pressure, instead of at constant volume. The motor piston moves out gradually under the steady pressure of the flame, instead of remaining practically stationary while an explosion takes place behind it and drives it out. This is the cycle used in the Simon en and a few others, and is much recommended by many autho The explosion occurs in a separate chamber, apart from the

cylinder, and the piston is, therefore, not much affected by the heat, and wears better. The discharge of the exhaust gases is also carried out in this chamber, and only admission and expansion of the charge take place in the compound motor cylinder. All the organs of admission, distribution, and ignition are at the crank, instead of at the further end of the cylinder. A centrifugal governor acts on the gas admission valve, and is very sensitive. In engines having an impulse at every revolution, lower pressures and lower speeds can be used than where a motor impulse is only given every two strokes, and a corresponding diminution in wear and in friction is obtained. The Trent engine is said to be very easily started. The consumption of gas is also low. Tests made of a nominal 4 H.P. engine, indicating 10·2 H.P., gave a consumption of less than 18 cubic feet per I.H.P. per hour. For a small power engine, these results are noteworthy. See drawings in *Engineering*, June 26, 1891.

**Robson's Shipley.**—Mr. John Robson, of Shipley, makes a small single-cylinder type termed the "Nonpareil" or Shipley, constructed on the same principles, and using the same cycle as the Otto. Ordinary lift valves and hot tube ignition are employed, and the engines are made horizontal for larger, vertical for smaller powers. The gas, admission, and exhaust valves are worked by cams on the side shaft, geared to the main shaft in the usual proportion, and there is no timing valve. No special feature in this engine requires description.

**Trusty, Premier.**—The "Trusty" horizontal engine, by Weyman & Co., of Guildford, and the "Premier," made vertical and horizontal by Messrs. Wells, of Sandiacre, near Nottingham, are both single cylinder engines, using the four-cycle, like the Shipley, and having an explosion every two revolutions. The valves of the Trusty are worked by a side shaft gearing into the crank shaft; the Premier is driven in the same manner. Both engines have hot ignition tubes without a timing valve, and run at 160 to 180 revolutions per minute. An inertia governor is employed in the Wells engine. It consists of a bar with a weight at one end, and a notched jaw at the other, attached to the lever opening the gas valve. Above the bar is a disc rotating at the same speed as the engine. Each time the disc completes a circuit, a pin upon it is brought round to the jaw, and entering it, pushes down the bar, and opens the gas valve. But if the disc rotate at too great a speed, the pin upon it slips past the jaw, and no gas is admitted. The Trust[illegible] the Shipley, and the Premier engines were exhibited at the A[illegible]ltural Show at Doncaster, in June, 1891. N[illegible] them [illegible] to be made in sizes exceeding [illegible]

[illegible] ontal single-cylinder engine, [illegible] repetition of the Otto, [illegible] ked from a side shaft.

It is made in sizes up to 50 I.H.P. In all these engines, the simple construction of the valves is said to effect a considerable saving in the consumption of oil.

**Palatine.**—The Palatine Engineering Company, Liverpool, have introduced a vertical engine designed on a different principle to the ordinary type. The crank shaft and connecting-rod are enclosed in a hollow cast-iron chamber above the cylinder, into which the upper part of the piston is used to compress air. As soon as the exhaust opens, at the termination of the working or up stroke, the piston uncovers two ports in the cylinder wall, through which the compressed air enters, driving before it the exhaust gases, cooling the cylinder, and cleansing it of the products of the former charge. More perfect combustion is said to be obtained, as the purity of the incoming charge is not diluted by the unburnt gases from the previous explosion. The effect is apparently similar to that of the compressed air introduced in the German Benz and Daimler engines; a weaker mixture than usual can be employed, and the consumption of gas thus economised. The gas enters the cylinder from a small pump, the piston of which is worked by wheels from the main shaft, and delivers a certain quantity per stroke in proportion to the air admitted; the amount is regulated by a centrifugal governor. The engine runs at from 200 to 350 revolutions per minute. Hot tube ignition is used, the valve to fire the charge being worked by a rod from the crank shaft. The principle of the Palatine engine, although not quite novel, is ingenious, and expansion is probably greater than in motors of the four-cycle type. To utilise the upper surface of the piston to compress the air above it is undoubtedly an advantage, and the crank being covered in makes the engine more convenient for use in confined spaces. It is made in sizes of 5 and 6 H.P.

**Robey.**—The Robey horizontal engine is manufactured by Messrs. Robey & Co., of Lincoln (Richardson & Norris patents), for driving dynamos for electric lighting, and other purposes. It has heavy flywheels, and the ball governor, as usual with this class of motor, is extremely sensitive; it acts on the gas valve by means of a lever and small roller. The usual four-cycle is employed. Ignition is by a tube heated by a Bunsen burner, a double-headed valve with two seats is used to fire the charge, and great accuracy of ignition is obtained. In the latest engines there is no timing valve. The number of revolutions can be readily altered, and the engine made to run, if required, at low speed during the day, and at a high speed at night. A patent "safety combination" is provided to prevent starting backwards, and by altering the eccentric lever the motion of the engine can be reversed. Coming from so well known a firm, this motor will probably be successful. It is well designed and constructed, and is already made in various sizes.

Two types, chiefly horizontal, are used. The first, in sizes from 2 to 86 B.H.P., runs at 160 to 230 revolutions per minute; the second, intended for electric lighting, is from 9 to 27 B.H.P., and the speed varies from 200 to 230 revolutions per minute. According to the makers, the cost of working these engines is 1d. per H.P. per hour. Drawings are given in *The Engineer*, October 14, 1892.

**Various Engines.**—Other motors employing the four-cycle, and generally resembling the Otto, with hot tube ignition and lift valves, are Woodhead's "Leeds," a vertical gas engine, the "Bradford" (horizontal), brought out by S. Clayton & Co. in 1882, and claiming to be one of the first engines using hot tube ignition without a timing valve; and the Purnell, a modification of the Turner, made at the Atlas Works, Blackfriars. The Capitaine, a vertical motor, having the cylinder with the ignition, admission, and governing valves above the crank, has been introduced from abroad, and a description will be found in the German section. In all these small engines, economy in the consumption of gas is not so much considered as solidity, compactness, and simplicity. No trials by independent experts have yet been made upon them.

**Day.**—Among modern English engines for small powers, one of the most simple and ingenious is constructed by Messrs. Day & Co., of Bath. In this little vertical motor several variations from the ordinary gas engine cycle have been introduced, and although most of them have appeared in other engines, they are here utilised in a new and original way. With one cylinder only, an explosion is obtained at every revolution. The cylinder and piston are at the top, and the latter works downwards upon the crank through a connecting rod. Instead of a pump, a reservoir is formed by enclosing the crank in an air-tight chamber, and through a channel or passage at the side the mixture is forced from it into the upper part of the cylinder. With the exception of this reservoir and charging passage, the mechanism of the engine is very simple. There is no counter shaft or eccentric, the action of the piston itself causing the admission and discharge of the gases. There is only one valve, through which the gas and air are automatically admitted, in proper proportions, by the suction of the up stroke of the piston. The exhaust gases are discharged through an opening in the cylinder, uncovered by the piston during the down stroke; ignition is by a hot tube without a timing valve, placed at the top of the cylinder. [illegible] explosion every revolution, there [illegible] ignition, the gases being driven [illegible] stroke by the compressing action [illegible]

Fig. 62 gives a sectional [illegible] engine. *a* is the hot ignition [illegible]

for the admission of gas and air, $d$ is the chamber enclosing the crank, into which the charge from $b$ is first drawn. At $e$ is the exhaust, which is merely an opening half-way down the cylinder, uncovered by the piston ; $f$ is the channel connecting the crank chamber with the working part of the cylinder. All the four operations of the Beau de Rochas cycle—admission, compression, explosion plus expansion, and exhaust, are performed in one down and one up stroke of the piston, the down being the motor stroke. The action of the engine is as follows :—The crank being at the lower dead point, and the trunk piston at the bottom of the cylinder, its edges just clear the port opening from the channel $f$ in the side into the upper end of the cylinder. Through this channel, during the latter part of the down stroke, the fresh charge, forced out by the piston, has been passing from the reservoir $d$. The up stroke now begins, and the port above $f$ is immediately closed; the upper face of the piston compresses the gas and air above it, and drives them up the ignition tube, $a$. Meanwhile, the reservoir having been emptied of its contents through the side channel, a partial vacuum is formed below the piston ; the automatic valve $b$ is lifted, and a fresh charge enters and fills the reservoir, $d$. The piston having reached the end of the up stroke, the charge is fired, and the expansion drives it down ; the exhaust port is uncovered and the gases discharged. When the piston has passed through half its stroke, it begins to force the fresh charge in the reservoir below it through the side channel into the upper part of the cylinder, before the exhaust port is covered. The incoming charge, already slightly compressed, helps to drive out the products of combustion. The return stroke compresses the mixture, and the cycle recommences.

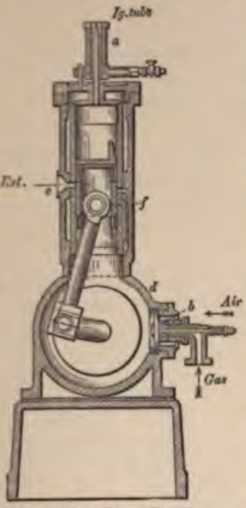


Fig. 62.—Day Engine—Sectional Elevation.

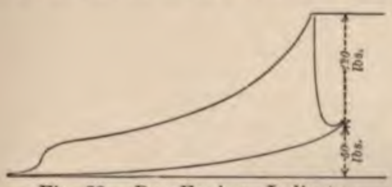


Fig. 63.—Day Engine—Indicator Diagram.

The simplic
Day engine makes it easy to reverse its directio
As there is only one automatic va
is to change the movement of

in the opposite direction. The original type is not suited to large powers, even when a twin engine is used, with a flywheel between the two cylinders. The speed varies from 150 to 400 revolutions per minute, according to the size. No trials have yet been made on this engine, and, therefore the economy claimed for it has still to be verified. Fig. 63 gives an indicator diagram of a nominal 1 H.P. engine, indicating 3·3 H.P. The diameter of the cylinder is $4\frac{1}{2}$ inches, stroke $7\frac{1}{2}$ inches, and it runs at 180 revolutions per minute. The Day engine is made in sizes from $\frac{1}{3}$ H.P. up to 24 H.P.

The "**Campbell**" engine, manufactured by the Campbell Company, at Well Field, Halifax, Yorkshire, is another example of a horizontal engine having two cylinders, motor and pump, and obtaining an explosion at every revolution. The pump is the smaller, and is worked by a crank on the main shaft. The latter also carries an eccentric opening the admission valve for gas and air. The vibrating pendulum governor acts by partial or total suppression of the gas. The hot tube ignition is at the back of the motor cylinder, and below is an automatic lift valve for admitting the charge from the smaller to the larger cylinder, in which it is compressed. The pump piston is at an angle of 90° in advance of the motor piston. The charge being first admitted through the flat valve, worked by an eccentric from the crank shaft, into the smaller cylinder during the out stroke of the pump, it is driven by the return stroke to the other cylinder. The motor piston being timed to move out later than the other, has not yet completed the in stroke, but the exhaust has already closed. A vacuum is formed, the automatic valve is lifted, the charge, already at a certain pressure, enters the motor cylinder, and is compressed during the remainder of the return stroke of the motor piston. The pressure drives the gases up the ignition tube, where they are fired; the charge explodes and forces out the piston. Thus we have admission in the smaller cylinder, and in the motor cylinder, expansion, discharge of the exhaust gases, and compression of the fresh charge. No trials appear yet to have been published upon this engine. It is made in sizes up to 50 I.H.P., and runs at from 150 to 180 revolutions per minute.

**Roots.**—The special feature of this engine, made by the Roots Economic Engine Company, is the compression of the gas and air. The charge is first admitted into a compression chamber, the suction stroke of the piston drawing a portion into the cylinder before the admission port closes. This portion is first fired the piston, driven out by the explosion, uncovers the port, the rich charge in the chamber is compressed, e pressure raised at once, and well maintained roke.

## CHAPTER XI.

## FRENCH GAS ENGINES—THE SIMPLEX.

CONTENTS.—Cycle—Electric Ignition—Slide Valve—Governor—Starting—Trials—Cheap Gas.

AMONG the various gas engines which have appeared during the last few years, to compete with the Otto, few have been as excellent in design, and as economical in working as the Simplex. It was brought out by MM. Delamare-Deboutteville and Malandin in 1884, constructed by MM. Matter & Cie. at Rouen, and owes the name of "Simplex" to its simplicity. The Otto firm contended that their patent had been infringed in France, and brought a law suit against the proprietors of the Simplex. In December, 1888, it was decided by the judges in favour of the latter. Although the Beau de Rochas cycle is used in their engine, and the method of operations resembles that of the Otto, several essential differences have been introduced, and the ignition, regulation, and self starter are on a new principle. One important modification has been made in the cycle, which the inventors claim as an improvement. Ignition takes place when the piston has moved a little, and not, as in the Otto and most other gas engines, at the dead centre, or before the piston has moved. The engine is horizontal, of the single cylinder, single-acting type.

**Simplex Cycle.**—In other respects the usual sequence is adhered to. There are four operations, each occupying one stroke, viz., 1st forward stroke, admission; 1st return stroke, compression; 2nd forward stroke, explosion and expansion; 2nd return stroke, discharge of the gases. Hence there is only one explosion for every two strokes forward and two strokes return, or every two revolutions, and one motor impulse in four. The compression space is more restricted, and the gases are more highly compressed previous to explosion, than in the Otto engine. Formerly, when ignition was effected by a flame carried in a movable slide valve, high initial pressures of the gases were difficult to manage, as the flame was frequently extinguished. For this and other reasons the electric spark is preferred to ignite the charge in this engine, and renders the pressure of the gases, as far as the force and certa[illegible] concerned, a matter of indifference. [illegible] compressed, as under ordinary conditio[illegible] as when starting the engine, ignitio[illegible]

effectual. This high initial pressure is a source of economy, because a poorer mixture can be used, less gas is required, the consumption is smaller, while with the gases at a higher pressure, as much work is done on the piston as if they were ignited at the dead point. The piston being allowed to move out a little way before the explosion takes place, works more easily and quietly. There is less shock at the bearings of the crank shaft, and not only the pressure of the gases, but the purity of the mixture is increased, and the products of combustion more completely expelled, because of the smaller space into which the charge is driven. It is true that the gases do not act upon the piston during the same length of time, but the pressure being higher, the inventors maintain that more power is obtained than when ignition takes place at the dead point, and that the mechanical efficiency is higher.

**Electric Ignition.**—After careful study of all the different methods of firing the charge in gas engines, MM. Delamare-Deboutteville and Malandin decided in favour of electricity. Their system obviates nearly all the drawbacks attaching to this method of ignition, except that a battery and coil are required to generate the sparks. The working expense of igniting by electricity is said to be about one-fourth less than the hot tube. Of all the many devices hitherto resorted to for firing the explosive mixture, none of them can be called perfect. The plan originally adopted by Otto, but since almost wholly discontinued, of carrying a lighted flame to and fro in the slide valve, was open to many objections. The great heat to which the slide valve was subjected, due not only to the internal explosions but also to the permanent gas flame burning outside, soon deteriorated the quality of the iron, made the joints brittle, and coated the joints with carbon. Ignition by a hot tube has not these disadvantages, but it is deficient in many ways. Unless the gases are at a very high pressure and temperature, they will not readily ignite. If the tube be made thick to resist this pressure, it will not become red-hot: if thin, its internal surfaces are continually exposed to the flame, while the external surface is at ordinary temperature. Hence these tubes require to be frequently replaced.

In France firing by electricity has been generally adopted. As employed by Lenoir and his successors, the system was defective, and there were frequent mis-fires. The positive wire from a Ruhmkorff coil was connected to the two opposite ends of the cylinder, the negative to the engine itself, and the circuit closed or interrupted by a contact maker. Premature ignition often occurred, and when the electric spark was generated inside the cylinder itself the points of the wires became coated, and sometimes no sparks were produced. The inventors of the Simplex have adopted the ingenious method of introducing the two ends of the wires into an isolated chamber

in the slide cover, and allowing a continuous stream of sparks to play between them. A slide valve moves to and fro between the slide cover and the cylinder, at half the speed of the crank shaft. At a given moment, a zig-zag passage in the slide valve is brought opposite the ignition chamber, and opens communication between it and the admission port into the cylinder. Part of the charge, already highly compressed by the back stroke of the piston, rushes through the passage, is fired by electric sparks, and ignites the mixture in the cylinder. The moment of ignition, therefore, is regulated, not by the generation of the electric sparks, but by the movement of the slide and the edges of the port. Premature ignition is prevented by isolating the wires in porcelain tubes.

To work well, this method of ignition requires a pure explosive mixture, and that no gases of combustion from the previous charge should be left in the firing chamber or the slide valve. At the moment when the compressed gases, driving before them any residuum of burnt products, pass from the cylinder into the oblique passage in the slide valve, and $\frac{1}{150}$ part of a second before the edges of the passage are brought opposite the firing chamber, a small hole opens communication with the outer air. This little vent-hole is obliquely in line with the firing chamber, to which it is connected by a grooved channel in the slide valve and face. So great is the pressure of the incoming charge, that all the burnt gases are discharged through this opening in even less than the time allotted, and the fresh purified charge is ready to be exploded. This system of ignition has been found economical and convenient. The slide valve and firing chamber are kept comparatively cool, and require less attention than with flame or hot tube ignition. The regulation of the speed is another special feature of the Simplex engine. Two ingenious methods are employed, according to the size of the engine; and the governors are novel in application, if not in principle.

Fig. 64 gives a side elevation, Fig. 65 a back view, and Fig. 66 a sectional plan of the Simplex engine. In outward appearance it somewhat resembles the Otto, having a single horizontal cylinder open at one end, working direct through a connecting-rod on to the crank, and a counter shaft to act upon the organs of admission, distribution, ignition, and exhaust, driven by worm gearing from the crank shaft. A is the motor cylinder, P the piston, C the connecting-rod, and K the crank shaft. E, Fig. 66, is the wheel on the crank shaft, and F another wheel gearing into it, of double the diameter, driving the side shaft R, which makes one revolution for every two of the crank shaft. B is the base plate, M the mixing chamber for the gas and air at the back of the cylinder. So far the construction is the same as in many other engines; the horizontal slide valve S, Fig. 66, is

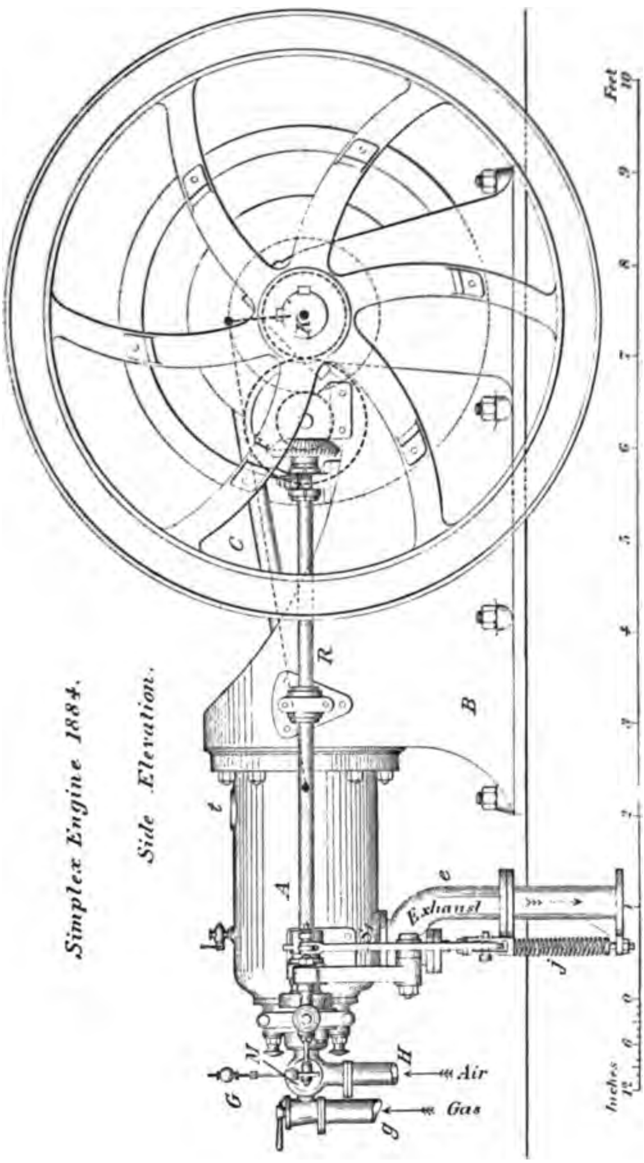



Fig. 64.—Simplex Engine—Side Elevation.

also driven to and fro by the side shaft R in the usual way. In Fig. 65, V and $V_1$ are the flywheels, and U and $U_1$ the pulleys.

The cylinder is cooled by a water jacket, the water enters at $t$, and is discharged at $t_1$, Fig. 66. $e$ is the exhaust opening at the bottom of the cylinder communicating with it through the valve $S_1$. The air enters at H, the gas at $g$, through a pipe at right angles to it, seen in Fig. 65. Both pass into the distributing chamber M, and from thence through slide valve S into the small chamber $B_1$ in the rear of the cylinder, where they are compressed by the back stroke of the piston. It is the relatively small size of this compression space in proportion to that of the cylinder which causes the gas and air to be more highly compressed than in most gas engines. In an engine of 6·7 B.H.P.

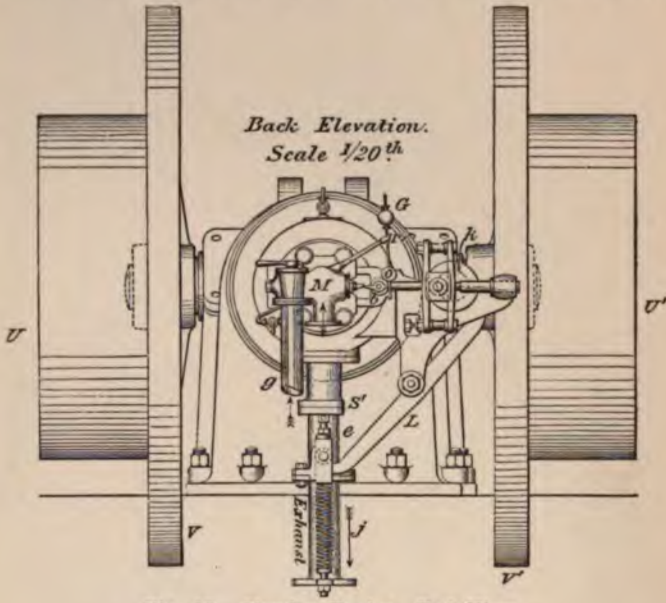


Fig. 65.—Simplex Engine—End View.

tested with town gas by Professor Witz, the volume of the compression space was 32·4 per cent. of the total cylinder volume. With gas of poorer quality, such as Dowson gas, the volume of the compression chamber is only 25·6 per cent., in the Otto engine it occupies about 36 per cent. of the total cylinder volume.

The side shaft terminates in a small crank, $k$, working the slide valve, and moving it once to and fro for every two revolutions of the crank shaft. The discharge pipe for the exhaust gases is seen at Fig. 64. The exhaust pipe $e$ is closed by the valve $S_1$, held upon its seat by the spring $j$. At a given moment

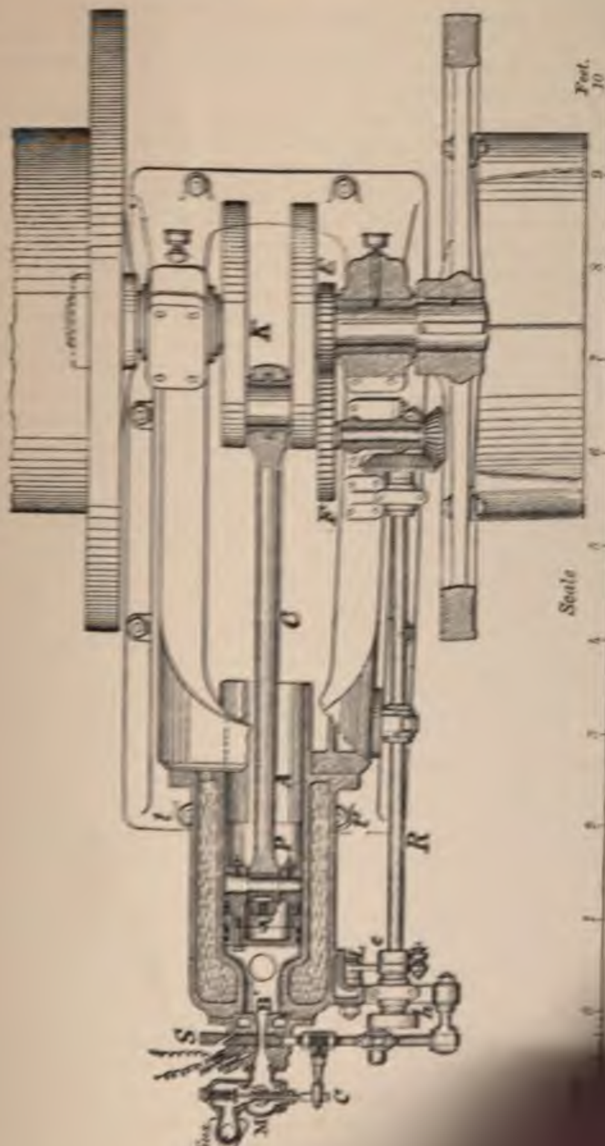



Fig. 66.—Simplex Engine—Sectional Plan.

a cam upon the side shaft R presses down one
L, the other end rises, releases the valve S,

and pushes it up, and the exhaust gases pass out through *e*. As the pressure in the cylinder is $1\frac{1}{2}$ atmosphere when the exhaust opens, the valve is lifted a little before the end of the stroke, to avoid back pressure on the piston.

**Slide Valve.**—Fig. 67 shows a sectional plan of the organs of admission, distribution, ignition, and the air governor, all of which are at the back of the cylinder. S is the slide valve, *k* the small crank on the counter shaft working it, and M the distribution chamber. This chamber has three openings, the first for the admission of air from below at H; the second, *g*, for the entrance of the gas, the valve of which is controlled by the air governor G to the right; the third leads through the slide valve into the cylinder, the arrows indicate the direction. At I is the ignition chamber, into which the ends of two electric wires surrounded by porcelain insulators are introduced, and a continuous stream of sparks plays between them, without heating the metal. The slide valve has only two openings, a rectangular passage, *e*, shown at Fig. 67, in line with the cylinder port and distribution chamber, and an oblique opening, *f*, which, as the slide moves to the right, brings the lighting chamber I into communication with the cylinder through the same port. The admission passage is first circular in form, then conical, lastly rectangular, and it is thus shaped to ensure the thorough mixing of the gas and air as they pass to the cylinder.

**Simplex Governor.**—Two simple and ingenious methods of regulating the speed have been adopted in this engine. For small motors, MM. Delamare and Malandin use an extremely sensitive air-barrel governor. If the speed be too great, the governor wholly cuts off the supply of gas, and this method is not only economical, but by admitting air only for one or more revolutions, the cylinder is thoroughly cleansed of the burnt products, and the next explosion is stronger, because the mixture is undiluted. The governor also regulates the supply when the engine is running light. The slide valve S, Fig. 67, carries a small horizontal cylinder, *c*, cast with it in one piece, and therefore making one movement forward and back for every revolution of the crank *k*, or every two revolutions of the crank shaft. The piston and rod of this cylinder are stationary and fixed to the slide cover, and the cylinder, contrary to the usual arrangement, slides to and fro over them with the movement of the slide valve. Rubber rings allow the piston-rod to move in a slightly oblique direction, as the cover is tightened against the slide valve. At the opposite end of the cylinder *c* is a small opening, *k'*, through which air is admitted and driven out by the piston at each forward movement of the slide; the quantity of air is regulated by a micrometer screw, and only so much enters at each stroke as will fill the cylinder. At right angles to, and cast in one piece with, the upper cylinder *c* and

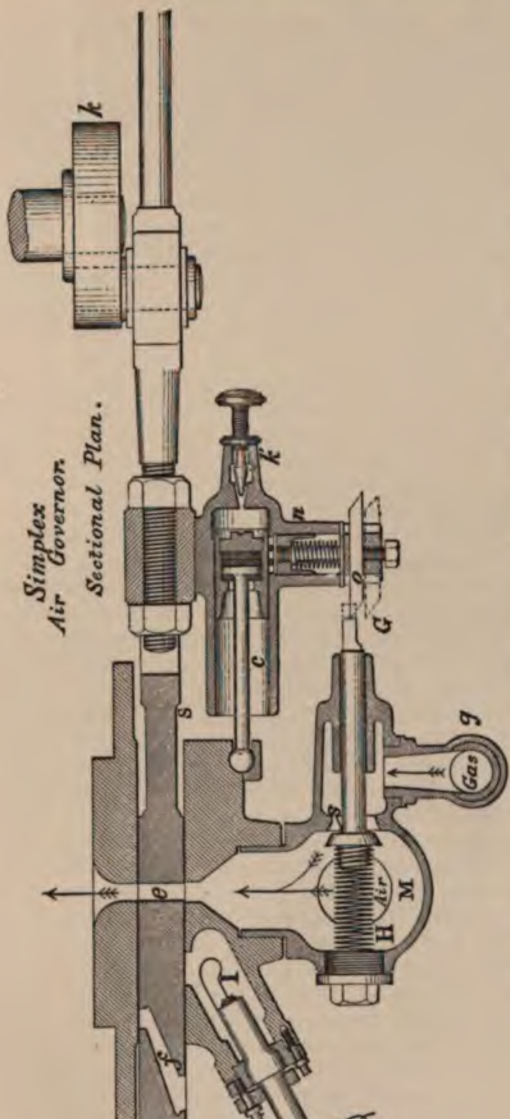



Fig. 67.—Simplex Engine—Section Plan of Admission Valves, Air Governor, &c.

the slide valve is a second smaller cylinder, *n*, the piston of which is free, and usually rests against *c*. The piston-rod ends

in a knife edge, *o*, fitting into the rod opening the gas valve. If the speed be normal, a cylinder-full of air is taken into and expelled from cylinder *c* at each to and fro movement of the slide valve. The piston of cylinder *n* does not move, and the knife edge *o* being brought each time by the motion of the slide against the gas valve-rod, pushes the valve open, and admits a certain quantity of gas. But if the speed be too great, the slide valve and, consequently, the cylinder *c*, make more than the given number of movements. More air is admitted into cylinder *c* than can be driven out during one revolution. It is compressed, the pressure acting upon the piston in *n* drives it down, and the knife *o* misses the edge of the gas valve-rod, as seen in the dotted line, Fig. 67. No gas can thus enter until the speed of the engine and, consequently, the pressure in the upper cylinder are reduced.

MM. Delamare and Malandin have lately introduced a modification of this method of governing, by which the speed of the engine can be still more delicately adjusted. With their air governor, as with most others, there is no alternative between admitting the full quantity of gas, and wholly suppressing it. Sometimes, however, the speed varies within such small limits that it is unnecessary to cut off the gas supply entirely. In such cases the speed is regulated by altering, not the amount of gas, but the quantity of total mixture admitted, the proportion of gas and air remaining the same. Thus the charge will always ignite, but, with the slightest increase beyond the normal speed, a weaker explosion is produced.

This effect is obtained by means of a rod through the centre of the mixing chamber M, Fig. 67, pierced with a hole to allow the spring of the gas valve *s* to pass across it, and terminating in two discs, one behind the other (not shown in the drawing), cut with alternate open and closed sections. The direction of the rod is the same as that of the arrows, and it carries a projection. The discs are placed across the chamber M, just before it narrows to the slide-valve port *e*. The inner disc is stationary, and fixed to the valve cover; the outer disc moves with the rod. Close to the projection, and held against it by a spring, is a small cylinder and piston communicating with the air-barrel cylinder *c*. When the engine is running at its normal speed, the openings in the discs correspond, and the mixture freely enters the cylinder from the chamber M, the small cylinder and piston remaining at rest. If the speed be slightly increased, more than the right amount of air enters the cylinder *c*, but not enough to drive down the piston in *n*, and wholly cut off the gas supply. This surplus air passe[illegible] into the small cylinder against the rod, drives up its piston [illegible] the projection, and the rod and disc attached to it m[illegible] The openings of the [illegible] smaller portion [illegible]

strength of the explosion is proportionally reduced. This method of varying the power of the engine within very small limits is applicable to any gas motor.

For larger engines a simpler and cheaper governor has been introduced. It is constructed on the principle of two pendulum weights, a lighter and a heavier, swinging on a fixed pivot at either end of a rod. The time occupied by the fall of the pendulum is always the same; the variation in the speed is obtained by a weighted knife blade acting upon the gas valve. Figs. 68 and 69 show the arrangement of the pendulum governor, also seen in Fig. 65. The two weights of the pendulum, Q and O, are mounted on a rod ending in a notch, N, and held in position

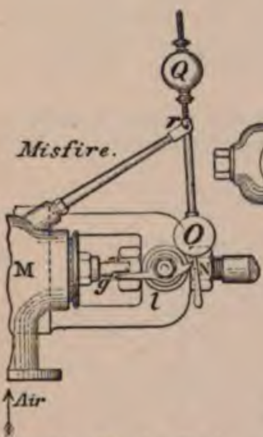



Fig. 68.—Simplex Engine—Pendulum Governor.

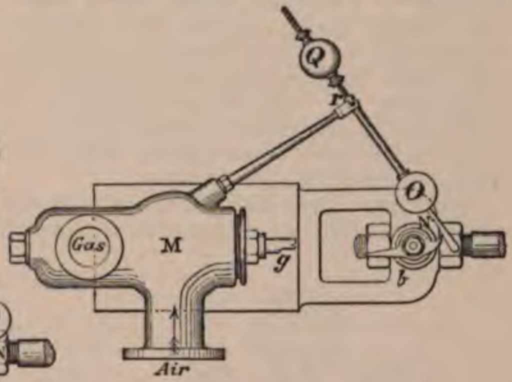



Fig. 69.—Simplex Engine—Pendulum Governor.

by the pivot *r* in the centre. The heavier weight O is fixed to the lower end of the rod; the upper and lighter weight can be adjusted by a screw to any distance from the middle of the rod, to give the required length of swing for any speed. The heavier weight being below, the tendency of the pendulum is always towards an upright position. Bolted to the slide valve of the engine, and therefore moving to and fro with it, is a frame carrying a knife blade, *b*, square and weighted at one end, and pointed at the other. The pendulum and the notched opening of the gas valve *g*, shown to the left, are both in the stationary valve cover, the weighted blade on the frame moves with the slide valve. As the square part of the blade is the heavier, the piece of iron, unless prevented, always remains vertical; but each time the knife blade in its motion encounters the pendulum as it swings, the point of the blade is caught by the notch and

held in position, and the square end of the knife pushes open the gas valve. If, however, the speed of the engine be too great, the slide valve carries the knife blade forward too soon, as seen in Fig. 68. The blade misses the notch, the weighted end drops below the gas valve, and no gas is admitted. This governor is almost as sensitive as the other, because, the fall of the pendulum being always the same, the regulation of the speed depends on the hit or miss of the notch.

From this description it will be seen that the Simplex engine differs in many important respects from the Otto, especially in the ignition, which, M. Delamare asserts, is simpler, cleaner, and more certain than the usual firing. The higher pressure obtained by reducing the compression space, the greater heat of the electric spark, and the more complete discharge of the exhaust gases, increase the economy and efficiency of the engine, and make it especially fitted for driving with Dowson or other poor gas. To set up a complete gas-generating plant, however, is only remunerative for large power engines, and it is under these circumstances that the Simplex reaches its maximum of economical working.

**Starting.**—The construction of the engine renders it easier to start than most other gas motors. As the electric spark is

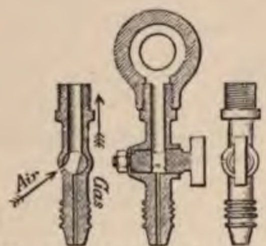



Fig. 70.—Simplex Engine—Starting Gear.


Fig. 71.—Simplex Engine—Positions at Starting.

sufficiently powerful to ignite gases at any pressure, preliminary compression, always a difficult matter, is not necessary to any large extent. A simple method of starting was introduced and patented by MM. Delamare and Malandin in 1888. A three-way cock, shown in plan, section, and elevation at Fig. 70, is connected to the ignition and main gas supply. The gas is admitted from below, and the air at the side into the ignition chamber, and pass through the oblique slide valve opening into the cylinder in the direction of the arrows. Fig. 71 shows a diagram of the movements of the piston.

The special and original feature of the Simplex self-starter is that the explosive mixture, instead of being introduced during

the admission stroke, enters the cylinder during the third or expansion stroke. All attempts to start the engine when admitting the charge as usual during the first forward stroke failed, because so long a time elapsed, viz., a forward (admission) and back (compression) stroke, before it was fired. But as soon as the "lucky idea," as the inventor calls it, was hit upon, of admitting the charge at the beginning of expansion, the engine was easily started, because the gases were immediately fired, and driven out during the course of the next exhaust stroke.

To set the engine in motion, therefore, the piston must be stopped at *c*, Fig. 71, at the end of compression, and the compressed gases allowed to escape. The gas cock and the three-way cock are then opened, and the flywheel turned by hand, until the piston has moved to *e* through three-quarters of its next forward stroke. Gas and air, mixed in the proportions allowed by the openings of the three-way cock, enter the cylinder to fill the vacuum caused by the forward motion of the piston. The cocks of both pipes are then turned off, the movement of the flywheel reversed, and the piston returning to $e_1$, slightly compresses the charge of gas and air behind it. The electric current is then switched on, and although the gases are at a low pressure, the spark is sufficiently powerful to ignite them, an explosion follows, and the engine is fairly started. For larger engines, where it is difficult to turn the flywheel by hand, the engine is started still more easily and simply. It must be stopped at *f*, Fig. 71, in the middle of the ignition stroke, and the gas and air allowed to enter through the three-way cock. At the top of the cylinder, above the compression chamber, there is a small hole closed by a pet-cock. This is opened, and the mixture of gas and air entering the cylinder at a slight pressure drive out, through it, the burnt products remaining from the previous charge. As soon as the hole is closed, the three-way cock being still open, the gas and air accumulate behind the piston and in the ignition chamber. The ordinary gas cock is then opened, a fresh charge enters, the current is switched on, an explosion follows, and the engine begins to move. In the later engines the pet-cock is replaced by an auxiliary cam on the counter shaft, which keeps the exhaust open and diminishes the pressure, until the engine is at work. In both these methods of starting the principle is the same, namely, to introduce gas into the cylinder by other than the regular means, and at an unusual period in the cycle.

The single cylinder 100 H.P. nominal Simplex engine attracted much attention at the Paris Exhibition of 1889, and was highly commended for economy and efficiency. Worked with Dowson gas made in a special generator, the consumption of coal per I.H.P. per hour was about half that in a steam engine of the same power. This engine was one of the best representative types then made of an economical gas motor. It

had two flywheels, each 5¼ feet in diameter, the diameter of the cylinder was 23 inches, length of stroke 3 feet 2 inches. The mean speed was rather less than the average, the engine running at 100 revolutions per minute, and the initial pressure of the gases 6 atmospheres. The mechanical efficiency was only 69 per cent. Few gas engines of the same H.P. are able to dispense with a second cylinder. In the opinion of Professor Witz, the success of this Simplex engine has established beyond a doubt that large power gas engines, when using cheap or Dowson gas, are able not only to compete with steam engines, but to surpass them considerably in economy. The saving effected by the use of Dowson gas, manufactured on the spot, instead of the expensive Paris gas, was very marked. MM. Delamare-Deboutteville and Malandin are now making engines, all single cylinder, to be worked with town gas, of the following sizes:— From 1 H.P. to about 150 H.P.; for Dowson or other poor gas from 30 H.P. to 150 H.P.

**Trials.**—Different sizes of the Simplex engine have been tested by Professor Witz. Trials of the 100 H.P. engine will be found in the table at p. 404.

These experiments were continued for four successive days, and the calorific value of the Dowson gas used was 1487 calories

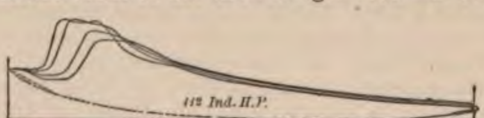


Fig. 72.—Simplex Engine—Indicator Diagram.

per cubic metre, at ordinary temperature and atmospheric pressure. The brake H.P. of the engine was 75·86, and the consumption 83·7 cubic feet of Dowson gas per B.H.P. per hour,

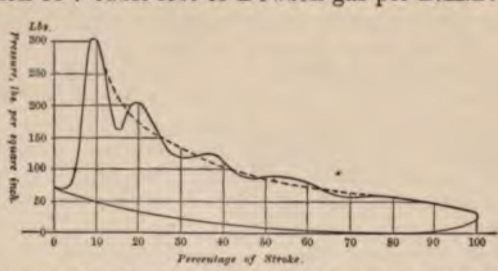



Fig. 73.—Simplex Engine—Indicator Diagram of 8 H.P. Fngine.

or 1·3 lbs. of coal per B.H.P per hour. Fig. 72 shows a diagram ᵉn during the trial. In a smaller engine tested by Professor z in 1885, the B.H.P. was 6·8, and the consumption of ary lighting gas 21·8 cubic feet per B.H.P. per hour. An

engine of nearly twice the size showed a brake consumption of 19·4 cubic feet per hour. Fig. 73 is a diagram from an 8 H.P. Simplex engine.

**Engines for Poor Gas.**—MM. Delamare and Malandin are still studying to perfect their engine, and have taken out 60 patents in France, and 10 in England. A list of the latter will be found in the Appendix. They have lately designed a new type with many modifications in detail, in which the calorific value of the gas is said to be much better utilised. The author regrets that the plans of this new engine are not yet sufficiently advanced for publication. Recently they have adopted the Lencauchez system of poor gas for driving their engines, and have erected several important installations in France, combining the Lencauchez generator and the Simplex engine. All of them are intended specially for burning poor and cheap coal. The system is described at p. 197.

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## CHAPTER XII.

## THE MODERN LENOIR AND OTHER FRENCH ENGINES.

CONTENTS.—Modern Lenoir—Charon—Tenting—Ravel—Forest—Niel—Lalbin—Various.

SINCE the introduction of his first motor in 1860, Lenoir, the pioneer of gas engines, had been incessantly working to perfect his invention and to remedy its defects, especially the large consumption of gas. Sixteen years later, in 1876, a new direction was given to the efforts of mechanical engineers by the appearance of the Otto. The success of this motor conclusively proved the truth of Beau de Rochas' theory, that, without compression of the gases before ignition, it is impossible to make an engine work economically. Abandoning, therefore, the lines on which he had formerly worked, Lenoir announced his adherence to the principle of compression by introducing, in 1883, an engine in which the Beau de Rochas cycle was closely followed.

**Modern Lenoir.**—Like the Otto, the modern Lenoir engine has one motor impulse in four. The first stroke (forward) draws in the mixture of gas and air, the second stroke (return) compresses the charge; during the third stroke (forward) it is exploded and expanded, doing positive work; and in the fourth stroke (return) the products of combustion are discharged. The cycle of this new engine is generally similar to that of the Otto, and like the inventors of the Simplex, Lenoir had to

encounter a lawsuit in France, which was decided in his favour in August, 1885. There are, however, essential points of difference, as well as of resemblance, in the two motors. Lenoir aims at obtaining higher compression of the gases. By separating the chamber in which they are compressed from the working cylinder, and keeping it hot, while the cylinder is cooled by a water jacket, he contrives to heat the gases before ignition, without unduly raising the temperature of the piston. As in the former engine, the electric spark produced for each explosion is employed to ignite the gases, but his particular method of ignition does not seem to give a perfectly regular speed. Whatever its merits when skilfully handled, it is, in the opinion of Professor Schöttler, a step in the wrong direction to fire the gases electrically. In other respects the mechanical details of this Lenoir engine are good, and carefully studied. The high pressure at which the gases are ignited gives greater expansion after explosion, the mixture can be much diluted or a poorer gas used, and greater economy is thus obtained. The piston moves out so little during explosion, that ignition practically takes place at constant volume.

The cylinder is in reality divided into two distinct parts, the motor cylinder, in which the piston works, and the compression chamber at the back, separated from it by an asbestos joint. This chamber, called by the inventor a "reheater," is a distinguishing feature of the engine. The cylinder is surrounded by a water jacket, but radiating cast-iron ribs, offering a considerable surface to the air, are sufficient to cool the compression chamber, because the piston does not enter it. Thus the incoming gases, as they pass through this chamber, which is much hotter than the cylinder, are heated prior to ignition, and the heat imparted to them increases their pressure. Before explosion it rises to 4 atmospheres (about 60 lbs.), and after explosion to 13 atmospheres, and to 16 atmospheres in engines using carburetted air. This high pressure and temperature make the gases ignite easily, although a poor and greatly diluted mixture is used. Another novelty in this engine is that the admission and ignition valves are at the side of the cylinder, in a relatively cool position, and therefore need little oiling. The electric wires never come in contact with the lubricant, and there is no danger of the ends becoming greasy. Air and gas are admitted and mixed in a distributing chamber, as seen in the drawing.

Fig. 74 gives a sectional plan of the modern Lenoir engine, ...ing the different parts. A is the motor cylinder, with ... P, B the compression chamber surrounded by the ex... ribs, E is the opening for the exhaust at the further end ... compression chamber, D the valve chest at the side of ...ylinder, containing chambers for the admission, mixing, and

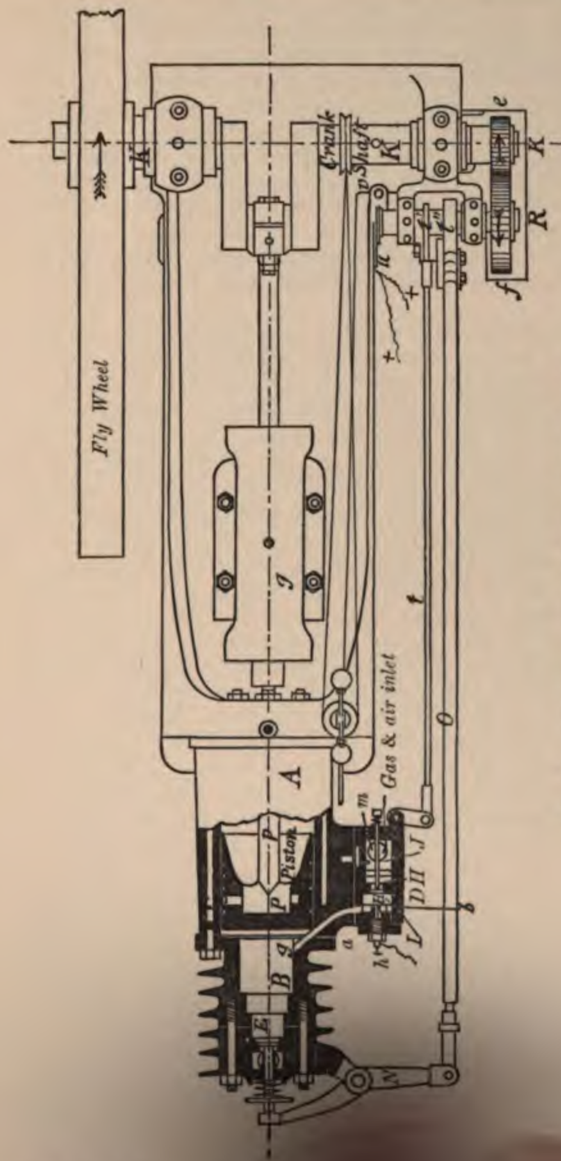


Fig. 74.—Modern Lenoir Engine—Sectional Plan.

ignition of the charge. At $a$ is t[illegible] joint separating the cylinder casting from that of [illegible] chamber to pre-

vent the conduction of heat. A portion of the piston-rod is seen at *p*, working through the connecting-rod and a strong cylindrical guide *g* on to the crank shaft K. All the organs of admission, distribution, ignition, and exhaust are worked by a counter shaft, R, driven from the main shaft by two spur wheels, *e* and *f*, in the proportion of 2 to 1. The shaft R, therefore, revolves at half the speed of the crank shaft. Upon it are two cams, $t'$ and $t''$, and a projection, *v*; these work the exhaust and admission valves, and the ignition. The exhaust E is opened by the lever N and the rod O. At a given moment the cam $t''$ on the counter shaft pushes out the valve-rod O, the lever N is displaced, and the exhaust port uncovered.

The valve chest D is divided into two parts, J the admission, and I the mixing and ignition chambers, and communication between them is made through a horizontal valve, H. The air enters from below at *m*, and the gas from above; the governor acts upon the gas admission pipe. To admit the gas into chamber J, the second cam $t'$ on the counter shaft R pushes out the rod *t* and lifts a valve placed on the gas supply pipe. Unless checked by the governor, the gas enters through several holes, and becomes thoroughly mixed with the air, before the valve H opens to admit the charge into the inner chamber I. From thence it passes through the channel *g* into the cylinder, and is compressed into B. The charge is fired at *h* on the same principle as in the earlier Lenoir motors. Two wires, positive and negative, pass from a Ruhmkorff induction coil, the one into the engine, the whole of which becomes negative, the other from *u* to *h* at the side of the admission chamber. Contact is interrupted or established by the projection *v* on the counter shaft R, which at a given moment in the cycle of the engine closes the circuit. The spark is produced, and part of the highly compressed charge in B, driven up the narrow passage *g* by the return compressing stroke, is ignited, and spreading back into the cylinder fires the remainder. The passage is always open to the cylinder, but the charge cannot ignite until the maximum pressure is reached, and the spark produced. An india-rubber bag is used to regulate the pressure of the gas. Little difficulty is apparently found in starting this engine, the process being always easier in engines firing electrically than in those which use flame ignition. The counter shaft R carries a second smaller cam, as well as the cam opening the exhaust, nd both can be brought into play when starting the engine. By ans of the second cam, the exhaust valve is opened twice during e revolution of the crank, to diminish the pressure of the gases the cylinder. As soon as the engine is at work, the handle oving this cam falls back automatically. The gas valve can lso be opened independently of the governor.

M. Tresca, who had been the first to experiment upon the original Lenoir motor, undertook two series of trials upon the modern engine, driven alternately with gas and with carburetted air. Tests were made on a 2 H.P. nominal engine with Paris gas in 1885, and the mean of three experiments gave a consumption of 24 cubic feet of gas per B.H.P. per hour. The indicator diagram is shown at Fig. 75. The engine ran at 176 revolutions per minute, and the mechanical efficiency was 74 per cent. The dimensions of the cylinder are given in the table, p. 402. Another experiment was made in 1890 by M. Hirsch on a 16 nominal H.P. Lenoir engine, in which the consumption of Paris gas per B.H.P per hour was a little over 21 cubic feet. It must not be forgotten that in all engines firing the charge electrically, the consumption of gas is slightly less than where flame ignition is used, because in the latter case a small quantity of gas is required to feed the light. M. Tresca died before the results of his experiments were published. The constructors of the Lenoir engine claim for it an average consumption of 23 cubic feet of gas per I.H.P. per hour.

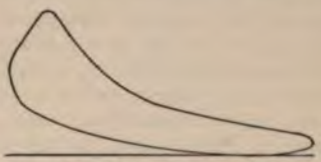

Fig. 75.—Modern Lenoir Engine —Indicator Diagram.

For sizes above 8 H.P., the Lenoir motor is usually made with two cylinders and pistons, working upon the same crank shaft. A single counter shaft between them drives the admission and ignition valves and the governor. There is only one mixing chamber, communicating alternately with each cylinder, and one commutator, to pass the spark to either cylinder as required. One explosion per revolution of the motor crank is thus obtained. Sometimes all the parts are made in duplicate, and the engine virtually consists of two single cylinder motors. The Lenoir engines are made at Paris by MM. Rouart Frerès, and by the Compagnie Parisienne d'Èclairage au Gaz.

**Charon.**—The Charon engine, surnamed the "Incomparable," was patented in 1888, and shown in the French Section of the Paris Exhibition of 1889. It is a horizontal four-cycle single cylinder engine, resembling the Otto in outward appearance and mechanical details, with lift valves and electric ignition. To obtain greater expansion in proportion to admission and compression of the charge, a novel feature is introduced in the construction of the engine. The student will already be familiar with various devices of this kind, but the method employed by M. Charon, although original, is complicated, and cannot be considered as offering a successful solution of the difficulty.

As in most types of engine using the Beau de Rochas cyc the piston makes two forward and two return strokes for

revolutions of the crank. The first out stroke of the piston draws in the charge, the second return stroke compresses it. The gas and air are then fired by the electric spark a little before the end of this stroke, and the charge is exploded before the piston begins its third stroke (out). The whole of this stroke is utilised in expansion, and during the fourth stroke (return) the products of combustion are discharged. The novelty of the engine is that, when the piston has reached the end of the first out stroke, the cylinder behind it being full of gas and air, the gas valve closes, but the air admission valve remains open during the first part of the return compression stroke. This valve communicates, through a pipe, with a circular spiral passage or coil in a chamber below. The other extremity of this coil is open to the atmosphere, and the air is drawn in through it. A portion of the gases, instead of being compressed in the cylinder, pass through the valve, and are stored up in the spiral passage. The valve then closes, and during the remainder of the second stroke (return), the charge is compressed by the piston in the usual manner. At the next admission stroke the air valve again opens, as well as the gas valve, to admit a fresh charge. Air is drawn in from the coil by the suction of the piston, carrying along with it to the cylinder the gases stored from the previous charge. The next compression stroke refills the spiral coil, the diameter and length of which are so proportioned that the compressed gases are prevented from reaching the opening, and escaping into the atmosphere.

The operations of admission, ignition, and exhaust are effected by lift valves, worked by cams on a side shaft. The cam opening the gas valve is controlled by the governor. The electric wires are carried into a small chamber at the back of the cylinder, immediately above the admission valve. Contact is interrupted by a lever moved by a cam on the side shaft, and the spark is produced just before the crank reaches the inner dead point. Extreme care is taken in this engine to determine the precise moment of ignition. The exhaust and air admission valves are driven from a small shaft at the back of the cylinder, at right angles to the side shaft, to which, at each revolution of the latter, an oscillating movement is communicated by two cams. The speed of the engine is ingeniously regulated on the following principle:—The governor acts, not only on the gas admission cam, but upon the cam opening the air valve. The greater the speed, the longer this valve is kept open. More of the gas and air pass into the spiral coil, less are retained to be compressed in the cylinder. Thus the charge will be poorer in quality and less in quantity, until the speed is reduced within normal limits. The exhaust valve is the same in principle as in the Otto engine.

A 4 H.P. Charon engine was tested in 1889 at Solre-le-

Chateau, France, by Professor Witz, and the consumption was found to be 19 cubic feet of gas per hour per H.P. Details of the experiment are not given, because the results were not considered satisfactory. Full drawings of the engine will be found in Witz and Chauveau.*

**Tenting.**—The Tenting, made by MM. Salomon and Tenting, at Paris, is a horizontal single-cylinder engine, simple in construction, and using the Beau de Rochas cycle. There is no slide valve. Admission of the charge is effected from a central opening below the cylinder, through which passes the rod of an automatic valve, held back by a spring. Gas and air, in proper proportions, enter the cylinder through a series of concentric holes below this valve. It is lifted by the suction of the motor piston during the admission stroke, and closes when the pressure in the cylinder, during compression and exhaust, is greater than that of the atmosphere. A valve-rod at the side of the cylinder, driven by wheels from the main shaft in the proportion of two to one, opens the exhaust valve. The centrifugal ball governor acts upon this rod through a lever. As long as the speed is normal, the lever rests against the cylinder; but if it be increased, the lever is drawn forward, and a projection upon it is interposed between the spring closing the exhaust and the valve-rod. As the exhaust valve cannot close, the pressure in the cylinder does not fall below that of the atmosphere, and the automatic admission valve is thus prevented from rising. No fresh explosive mixture enters until the speed is reduced, and the lever allowed by the governor to right itself.

This engine has no water jacket for powers below 4 H.P. The cylinder is surrounded by a hollow casing divided into compartments, through which air circulates, entering at the bottom, and passing out at the top. The air can be replaced by water if desired. Electric ignition was used at first in the Tenting engine. The negative wire was joined to any part of the engine, and contact was established between it and the positive wire by an isolated metallic column and a disc attached to the auxiliary shaft. At the moment of ignition, a small porcelain pin or insulator, carried round on the disc, interrupted the current, which passed to a point above the compression chamber of the cylinder; the electric spark was produced, and the mixture fired. Firing by electricity has now been abandoned in favour of hot tube ignition.

**Ravel.**—Two varieties of the Ravel engine have already been described, but the inventor has lately re-modelled the design. In 1888 M. Ravel introduced a horizontal engine of the Clerk type, giving an explosion every revolution. There is one mot[illegible] cylinder and piston. The cylinder is closed at both ends, [illegible]

* Gustave Chauveau, "*Traité théorique et pratique des Moteurs à* [illegible]

air is drawn in at the crank shaft end, and compressed into a reservoir in the base of the engine, while expansion is taking place on the other side of the piston. The gas is admitted into a separate pump, and compressed into a second reservoir before entering the cylinder. Each forward stroke is a motor stroke, and corresponds to one revolution of the crank. Although both gas and air are thus previously compressed, the pressure of the ignited gases and their consequent expansion is not so great as might have been expected, and is, to a certain extent, sacrificed to regularity of working. The exhaust openings are placed near the crank shaft end of the cylinder, and are uncovered by the piston, when it has passed through about two-thirds of the expansion stroke. The additional complication of the pump and reservoirs for the gas and air, and the deficient expansion, due to the early opening of the exhaust, are undoubtedly defects in this engine.

The construction is rather complicated. The air, after being drawn into the front part of the cylinder, and compressed through an automatic lift valve into the reservoir formed in the base plate, passes into the mixing chamber. The gas is first compressed in the pump, the piston of which is worked from the crosshead of the motor piston, then delivered into the small reservoir above the air reservoir, the pressure in both being the same. It then enters the mixing chamber, and two valves worked by a single rod, and opened by a cam on the crank shaft, admit the gas and air to the cylinder. Meanwhile the exhaust valve and lever, acted on by another cam on the crank shaft, are lifted. The immediate lowering of pressure, caused by the opening of the exhaust ports, draws in the mixture through an oblique passage, which gives it a spiral motion, helping to drive out the products of combustion. It is necessary to prevent part of the fresh charge from escaping with the exhaust gases, and this, according to the inventor, is effected by the circular motion imparted to the charge by the shape of the admission passage. The return stroke of the piston covers the exhaust ports, and the fresh charge is then further compressed. Just before the end of the stroke it is driven into a chamber at the back of the cylinder, the electric spark is produced, and the charge fired. Thus by the time the piston has reached the inner dead point, explosion has already taken place, and expansion follows. In this way the charge is twice compressed, and the pressure twice utilised. After being compressed separately by the auxiliary gas pump and the outer face of the motor piston, the gas and air enter the cylinder under their reservoir pressure, and clear it of the products of the former charge. The mixture is then compressed afresh by the motor piston, the charge is exploded, and drives the piston forward, doing work.

Notwithstanding these high pressures M. Ravel has preferred not to utilise fully the power generated for the expansion stroke,

but to employ moderate pressures, and to obtain a steady rate of working. He has also sacrificed economy to regularity in the action of the governor. A centrifugal governor is used, placed above the pipe admitting the gas to the pump, and the supply of gas is regulated according to the speed. A certain quantity is always allowed to pass through the cylinder, but if that quantity be too small to ignite, it escapes unburnt. The variation is in the quality of the charge, and the engine is said to work with great regularity, but somewhat extravagantly. In economy it is easily surpassed. The main objects aimed at by the inventor have been to produce an engine running so regularly that it can be utilised for electric lighting, and to obtain a working impulse every revolution, instead of every two revolutions, of the crank. In a trial made on an 8 H.P. engine, the highest explosive pressure was 8·6 atmospheres, and the consumption of gas (French) 33 cubic feet per I.H.P. per hour. The indicator diagrams show a low explosive pressure, but comparatively great expansion. By adjusting a screw on the governor, the balls can be raised or lowered, and the speed varied from 40 to 160 revolutions per minute. Drawings of this engine will be found in Witz and Chauveau.

**Forest.**—A new variety of the Forest engine, described at p. 71, was brought out at the Paris Exhibition of 1889. In this motor M. Forest has adopted the usual method of compression of the charge before ignition, the Beau de Rochas cycle is used, and an explosion obtained every other revolution. There is a single horizontal cylinder, having two motor pistons each attached to a lever, and moving in opposite directions. The crank shaft is above, and is driven by two connecting-rods, and two cranks 180° apart. The charge is admitted in the space between the pistons as they move out, compressed to 5 atmospheres, and ignited electrically. The explosion takes place between the two pistons, forcing them apart, and acts through the levers upon the two cranks. Greater compression is thus obtained, but otherwise the engine does not seem to have much to recommend it. It is a compact little motor, but there are a good many moving parts. A drawing will be found in Witz. M. Forest has devoted his attention more particularly to marine and petroleum engines, with reversible motion and automatic starting gear. These will be described in the Oil engine section.

**Niel.**—The Niel, which first appeared at the Paris Exhibition of 1889, is a well-designed horizontal single-cylinder compression engine of the Otto type, but with several ingenious modifications. The admission, distribution, and exhaust valves are worked from a side shaft geared from the main shaft by worm wheels as usual. The exhaust is only a vertical lift valve; the admission gear is novel in principle and arrangement. It

consists of a conical revolving valve which, when brought to face the cylinder ports, governs the admission and compression of the charge. The gas and air enter the cylinder through openings in the valve. By this rotatory movement the charge is drawn in, usually in the proportion of 1 of gas to 8 of air, by the forward stroke of the piston. To reduce the shock, and make the engine work more smoothly, admission lasts only during two-thirds of the first forward stroke and the charge expands slightly during the last third. Thus admission is less in proportion to expansion, but this advantage is counter-balanced by the correspondingly smaller compression. The effect of this variation from the usual cycle is seen in the diagram, where the admission line falls at the end slightly below atmospheric pressure. In the return stroke the conical valve opens communication between the contents of the cylinder and the hot ignition tube. It is during this period of compression and explosion, that the difficulty of preventing leakage is experienced with all slide and rotating valves. M. Niel obviates it in an ingenious way, and even turns it to account. A thin

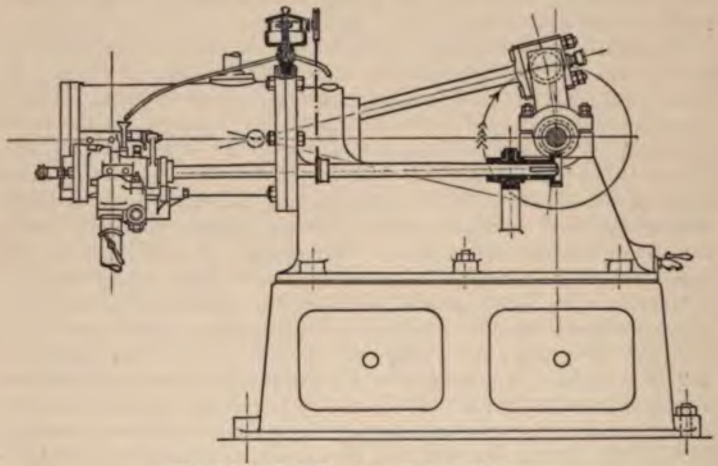

Fig. 76.—Niel Engine—Sectional Plan.

metallic diaphragm in the conical valve is so arranged, that it is acted upon by the pressure of the gas in the cylinder. Thus the valve is made to fit more closely in its socket when the pressure in the cylinder is at its maximum, the pressure on the conical part is then greatest, and leakage is minimised. The discharge of the gases does not take place through this valve, but through an ordinary vertical lift valve, opened by a lever below the cylinder, and a cam on the side shaft. Fig. 76 gives an

elevation of the Niel engine, showing the side shaft and method of driving it, the conical distributor, ignition, and oiling apparatus; the exhaust is on the opposite side of the cylinder.

The oscillating governor consists of three arms, one of them weighted, moving round a fixed point. Under normal working conditions, one of the arms at each revolution reaches and opens the gas admission valve; but if the speed be too great the arms are thrown out of position, the valve is missed, and no gas admitted. The speed is regulated in somewhat the same way as in the Simplex pendulum governor. Drawings of all the different parts of this engine, and a complete description by M. Auguste Moreau, will be found in *Comptes Rendus de la Société des Ingénieurs Civils*, October, 1891.

**Trials.**—A series of careful experiments upon a 4 H.P. nominal Niel engine were made by M. Moreau. An indicator diagram taken during the trial is given at Fig. 77. The temperatures of the gases and of the water in the jacket were determined, and nothing was omitted to make the experiment as complete as possible. M. Moreau found that, when running at 160 revolutions per minute, with a maximum pressure of 12 to 14 atmospheres, the mean consumption of Paris gas was 27·2 cubic feet per hour per B.H.P., but the engine was of an early type, and the construction has since been improved. The mechanical efficiency was 75 to 80 per cent. The Niel engine is compact, and works regularly and quietly. More than one hundred of these motors, a large number for France, are said to be now made in the course of the year, but mostly for small powers.

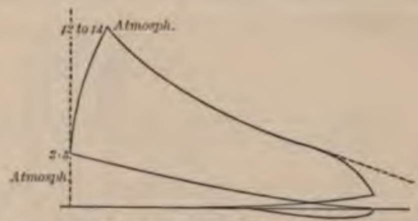

Fig. 77.—Niel Engine—Indicator Diagram.

**Lalbin.**—The Lalbin exhibits a new and ingenious type of gas motor, with three cylinders. M. Lalbin's object has been to construct an engine small in size, combining the maximum power with lightness, and his 8 H.P. motor weighs only 770 lbs.; he has also succeeded in making it reversible, and applicable to gas, oil, or carburetted air. It is a four-cycle engine with three motor pistons, all working upon the same motor crank through connecting-rods, with their three cylinders arranged equidistant round a circle. The complete cycle is carried out in each cylinder in two forward and two return strokes, and is so arranged that three motor impulses are imparted to the crank during two revolutions, and therefore a small flywheel is sufficient. The motive power is more uniform

than is usual in gas motors, and only one-sixth of a revolution intervenes between each stroke. Fig. 78 gives a sectional elevation of the Lalbin engine, showing the three cylinders and pistons, with the crank in the centre. Each cylinder is complete in itself, and has its separate valves for admission, ignition, and exhaust. The admission valves are automatic; tube ignition is used when the engine is worked with gas, and electricity when driven with carburetted air. These features are to be found in other engines, but the exhaust valves are original in design. They are opened by a cam on a disc revolving with the crank shaft, but as they require to be lifted only once every other revolution, an ingenious hit-and-miss contrivance has been adopted. During one revolution the valve-rod misses the disc, the next time it fits into it, and the exhaust is opened. The engine is easily reversed by turning the disc in the opposite direction, and making the ignition of the charge take place a

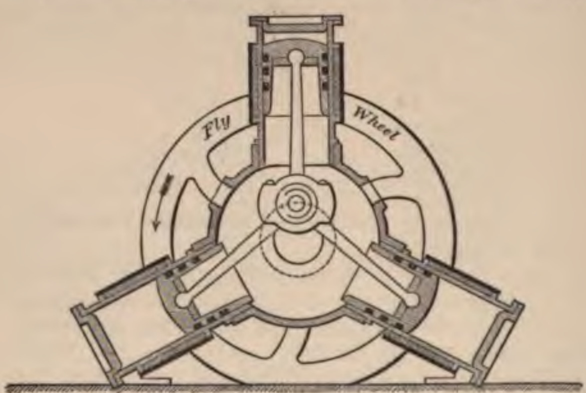


Fig. 78.—Lalbin Engine—Sectional Elevation.

little sooner. The Lalbin is a new engine, and still on its trial. Time alone can show whether this three-cylinder arrangement has any practical advantage over the single-cylinder type, and whether, as M. Witz thinks, the engine has a great future before it. Probably the mechanical efficiency will be low. Full details and drawings are given in Witz, p. 311.

The Diederichs engine, manufactured by the firm of Belmont, Chabond & Diederichs, at Bourgoin, Isère, France, will be described among the petroleum motors. It is seldom worked with gas.

**Various.**—A few of the engines already mentioned in the historical chapters are still occasionally made in France. These are the Bénier, Étincelle, the Noël, and the François. Others have only a local reputation, as the Cazal, Delahayes, Poussant,

Roger, Letombe; le Robuste, made at Evreux, and the Mille at Lyons. The relatively small number of gas engines constructed in France, with the exception of the Simplex and the Niel, is in striking contrast to the much greater number and variety made in England, and is probably due to the higher price of fuel and gas in France. This accounts for the popularity of the Simplex engine, which is especially adapted for working with cheap gas. MM. Delamare and Malandin are said to supply from one-third to one-half the gas motors produced yearly in France. English and German engines are also imported.

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## CHAPTER XIII.

# GERMAN GAS ENGINES—THE KOERTING-LIECKFELDT, ADAM, AND BENZ.



**Koerting-Lieckfeldt.**—Next to the Otto, no gas engine is so popular or so extensively made in Germany as the Koerting-Lieckfeldt. It was first brought out in 1879, and is, therefore, one of the oldest surviving gas motors. Since then many improvements have been introduced, and the mechanical details are constantly undergoing alterations. It has been shown with successive modifications at nearly every exhibition during the last ten years. Nevertheless there are two or three important and original features which re-appear in the different types with scarcely any variation. The chief of these are the vertical disposition of the cylinder, the method of ignition, and the regulation of the speed.

The principal advantages of vertical gas engines consist in the smaller floor space occupied as compared with horizontal motors, their smaller weight and greater simplicity. For this reason, since space is often of importance, various attempts have been made to utilise the vertical type, and make it work satisfactorily. Of these the most successful is the Koerting-Lieckfeldt, but, in common with all other motors of this class, it has some defects. Engines with vertical cylinders have not generally been found practical for larger powers, while for medium and small powers there is a good deal of vibration at high speeds. If a motor giving more than about 10 H.P. is required, either a second cylinder must be added, or the engine made horizontal.

The method of ignition in this engine is by propagation of

flame in a special conical tube. At the time of its first introduction by MM. Koerting and Lieckfeldt it was a novel idea, though it has since been extensively copied. It is based on the principle described in the following terms by M. Chauveau:—"If a certain volume of gas communicates through a conical tube with the atmosphere, its largest diameter being open to the air, and if the gas be allowed to escape at a certain speed, the pressure in the tube decreases towards the mouth, where it will be about equal to the atmosphere. If the gas as it issues from the tube be ignited, the flame will spread back to the point where its speed of propagation equals the velocity at which the gas is escaping. Here it will remain stationary unless, at a given moment, the mouth of the tube be suddenly closed, when the remainder of the gas will ignite, and a jet of flame be projected into it." The principle has been utilised with excellent results to ignite the gases in this engine, though ordinary hot tube ignition is also employed.

The third novelty introduced is the method of regulating the speed. If the normal number of revolutions be exceeded, the governor acts upon a lever, one end of which keeps the exhaust valve open, while the other holds a return valve in the mixing chamber closed. To govern the speed by thus acting on the exhaust, is only applicable where the gas and air are admitted through an automatic lift valve. It is the vacuum caused by the discharge of the gases which lifts the admission valve, and allows a fresh charge of gas and air to enter. If a return valve is used, to prevent the ignited gases from striking back into the mixing chamber, it acts only during the pressure of explosion, and does not lift if the exhaust be held open by the governor. To make it close more securely, however, the inventors of this engine have added a lever to hold it down. The result is, that not only pure air, but the discharged products are drawn into the cylinder at the next stroke, and this continues till the speed is reduced, and the governor releases the exhaust valve.

There have been two distinct periods in the construction of the Koerting-Lieckfeldt engine. In the original type of 1881 an auxiliary pump was introduced, the four operations of admission, compression, explosion plus expansion, and exhaust were divided, as in the Clerk engine, between the two cylinders, and an impulse obtained at every revolution. The two vertical cylinders (pump and motor) were placed side by side, the motor piston working upwards on to the first crank on the main shaft, the pump being driven by a second crank on this shaft. Between the two cylinders was an automatic lift valve, a return valve, and the ignition chamber, all similar in construction and arrangement to those in the present engine. The exhaust valve was on the opposite side of the motor cylinder. The down stroke of the pump compressed the gas and air,

and the pressure lifted the admission valve. The charge was driven through it, and past the return valve, and ignited in the lighting chamber, the force of the explosion driving up both pistons. The mixture expanded in the motor cylinder, doing positive work on the piston, while the pump drew in a fresh charge. Professor Schöttler is of opinion that this arrangement must have had one disadvantage. Owing to the pressure of the gases in the pump, there was probably some leakage past the return valve, which could seldom be made sufficiently tight to prevent a portion of the flame from shooting back into it. The method of governing the engine was original. If the speed was too great, the ball governor opened communication between the pump and a reservoir, into which part of the compressed charge was driven, and where it remained stored up. The pump clearance space was thus enlarged, and its compression space reduced, and at the next stroke the pump drew in a smaller charge. This increase of the clearance space by the addition of the reservoir continued till the speed of the engine had fallen to its normal limits. The construction of this engine, drawings of which will be found in Schöttler, has now been given up for that of the new type, brought out in 1888. The style of the firm has also changed, and it is now known as Koerting Bros., of Hanover; the present engine is called the Koerting.

**Type of 1888.**—In this motor the four-cycle of Beau de Rochas has been adopted, giving only one working stroke in four. There is a single motor cylinder, and in other respects the engine is very similar to the familiar Otto type, except in the ignition and governing, and in the vertical form of the cylinder. Fig. 79 gives a sectional elevation, and Fig. 80 a sketch of the method of ignition. In Fig. 79 the organs of admission, distribution, ignition, and exhaust are shown, ranged side by side towards the bottom of the cylinder. A is the motor cylinder, P the piston, *d* the connecting-rod, working direct on to the crank shaft K. All the valves, with the exception of the admission valve, which is automatic, are worked from a rocking shaft, *u*, running horizontally across the engine, and containing two levers. The crank shaft carries at the end a wheel *e*, gearing into another below it, *f*, of twice the diameter. With the latter revolves a second auxiliary shaft *c*, carrying two cams, S and $S_1$. These cams work, $S_1$ through the lever $T_1$ on the valve-rod $R_1$, and the ignition tube I, S through lever V on the valve-rod R, lifting the exhaust once during a revolution of the shaft *c*, or two revolutions of the crank shaft. Both the valves are, therefore, opened once in every cycle by the cams, and closed again by springs.

One valve chest encloses the valves for admission, distribution, and ignition. I is the ignition chamber, E the exhaust valve. The air enters at H from the base of the engine, in the direction

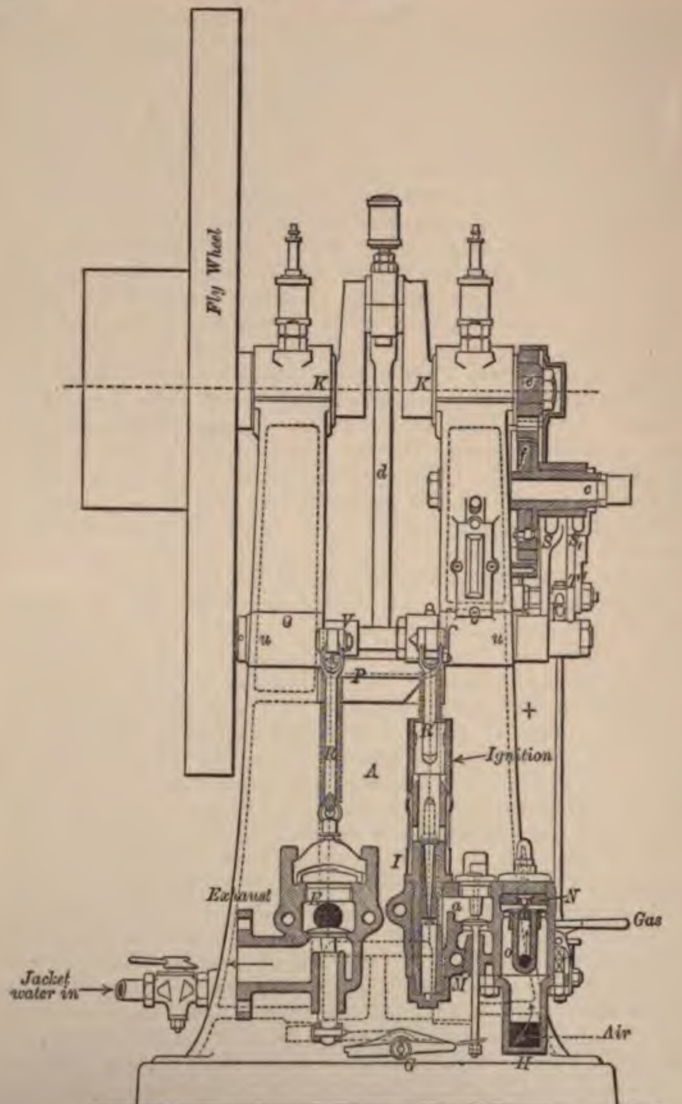


Fig. 79.—Koerting Engine—Sectional Elevation.

indicated by the arrows, the gas above it, and both mix at *o*. The automatic valve N is lifted by the pressure, and the gas and ...mbined before passing on to the cylinder.

It is a special feature of the Koerting engine that the charge is thus said to be perfectly mixed, instead of entering the cylinder in stratified layers, as in the Otto. As the governor acts upon the exhaust, instead of the gas valve, the quantity of gas and air entering the cylinder is always in precisely the same relative proportions. The charge then passes into the cylinder at *a*, the automatic admission valve N being closed, and the return valve M held down on its seat. As soon as the down stroke of the piston compresses the gases into the ignition chamber, the valve M rises to prevent the flames from shooting back into the mixing chamber. Fig. 80 gives a sketch of the method of ignition. A small chamber communicating with the motor cylinder is in two hollow divisions, the lower *b* fitting into the upper *d*. The larger *d* has an opening at the bottom, *h*, and a transverse groove above, *o*, opposite to which is the external flame B. The lower piece *b* usually rests upon the support *d'* and between it and *d* is a small longitudinal space or aperture, *m*, forming a continuation of *h*. Enclosed within *d* and *b* is a cone-shaped tube in two parts; the upper *r* is solid, the lower *s* is hollow, and tapers towards the bottom, where it communicates during the compression and explosion of the gases with the motor cylinder through *a*. At other times the connection between the ignition chamber and the motor cylinder is shut off. *s* and *d* are the stationary, and *r* and *b* the moving parts. Before the end of the down compression stroke, the pressure of the gases drives up *b*, closing the passage *m*, while the solid cone *r* is lifted by the valve-rod $R_1$ (Fig. 79). The lower piece having left its support $d_1$, the compressed gases rush up the narrow end of the cone *s*, and ignite at the flame B through the groove *o*; *r* is now driven down by the cam on the auxiliary shaft and the valve-rod $R_1$, and the part *b* descends, leaving the passage *m* free. The mouth of the cone being suddenly closed, while the compressed gases are still entering from below, the flame shoots downwards until the pressures are equalised. The ignited gases rush out through *m* and *h*, and fire the remainder of the charge. The pressure of the explosion firmly closes the return valve M.

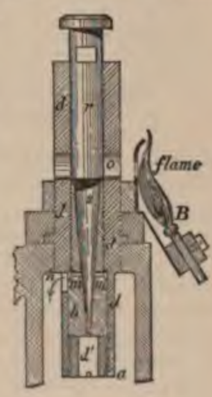


Fig. 80.
Koerting Ignition Valve.

**Governor.**—The exhaust valve E is worked by the valve-rod R, in the same way as the ignition valve by $R_1$, except when acted upon by the governor, as shown in Fig. 81. Upon the auxiliary shaft *c* is a weight, *n*, revolving at the same speed as the counter shaft round a fixed point, and held in position

by a spring, *s*. If the speed is normal, the weight does not interfere with the working of the valve, which is regularly opened once in every revolution of *c* by the cam S. But if the proper speed be exceeded, the weight rotates too rapidly, projects outside the plane of the wheel, and pushes forward a bell crank, *l*, carrying a notch at *q*. This notch catches in a projection on the lever *v* at the moment when it is pushed down by the cam S; the lever *v* and the valve-rod R are raised, and the exhaust valve lifted. Until the speed is reduced, and the weight sets the catch free, the lever cannot release the valve, and return to its original position. At the same time, the opening of the exhaust valve raises the left arm of a rocking lever, shown at G, Fig. 79, and the other arm holds the return valve M closed. No fresh charge can, therefore, enter the cylinder until the exhaust valve-rod being released, the lever G regains its position. During this time only the products of combustion will be drawn by the suction of the up stroke into the cylinder.

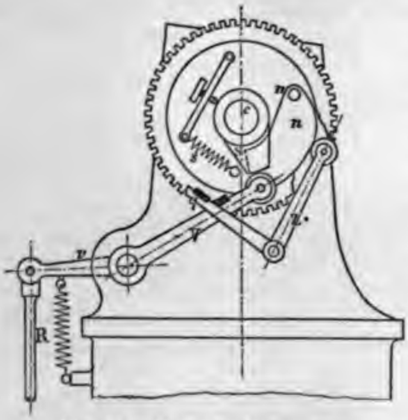

Fig. 81.—Koerting Governor—Elevation.

In some cases the cooling jacket water is a difficulty. To meet this case, the inventors have introduced an apparatus for economising the supply, which occupies little space, and can be fixed against a wall near the engine. It consists of a series of cast-iron pipes with external ribs, into which water drawn from a reservoir is sent, and passed on into the cylinder jacket. As soon as the cylinder becomes hot this water rises into the upper part of the pipes, and is replaced by cooler water. Between the pipes and ribs a circulation of air is induced, thus cooling the water, which can be used continuously for hours. The hot air is either discharged into the atmosphere, or used to warm the building. The oiling of the engine is effected automatically in the usual manner.

**Horizonta** —MM. Koerting have lately brought out
**a new horizo** : of the usual four-cycle type. In this
**engine hot t** ... is used with a Bunsen burner. An
**outer porcel** ... ery small inner platinum tube, kept
**at a red he** ... compression stroke the tube com-
**municates t** ... with the outer air, discharging the

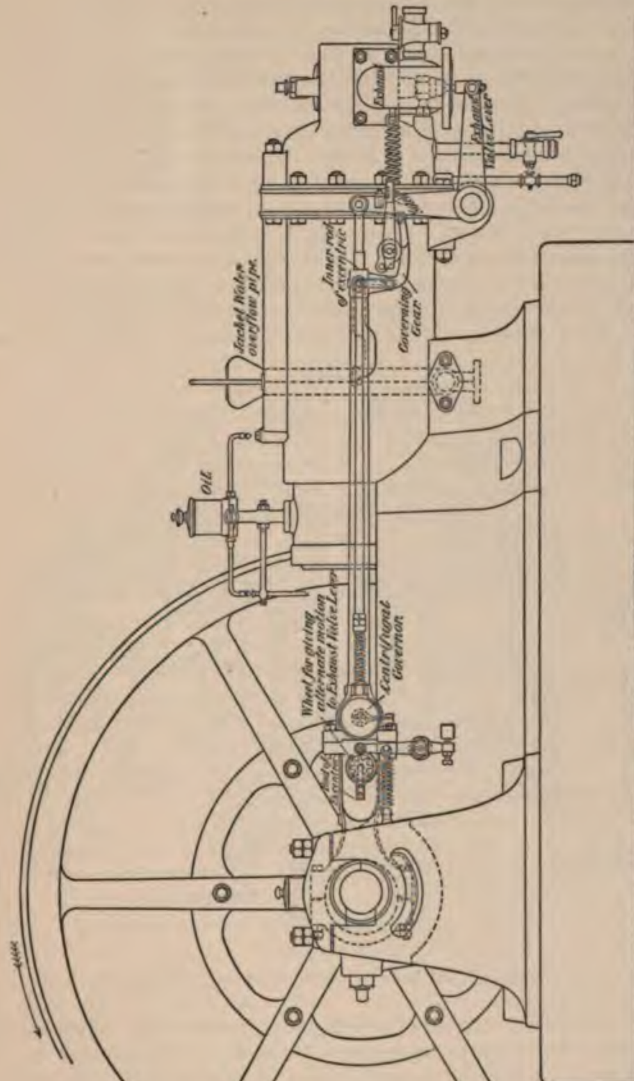


Fig. 82.—Koerting Horizontal Engine.—Elevation.

products of combustion. The velocity of the gas entering the ignition chamber is said to be so great, that the flame does not

spread back into the cylinder until the outer valve is closed, when it shoots forward, igniting the remainder of the charge. The valves resemble those of the vertical engine, except that they are worked by eccentrics on the crank shaft. There are three valves; the first is automatic, and through it the gas and air enter the mixing chamber, the second admits them to the cylinder, the third is the exhaust. A lever acted upon by the pendulum governor works, as already described, between the exhaust and the admission valves, and as the one is lifted it holds the other closed. The weight is carried on the eccentric opening the exhaust valve. If the speed becomes too great, it acts through levers upon a notch catching in the exhaust valve-rod, and prevents its closing. As the eccentrics revolve on the crank shaft, they would, if not prevented, open the valves at

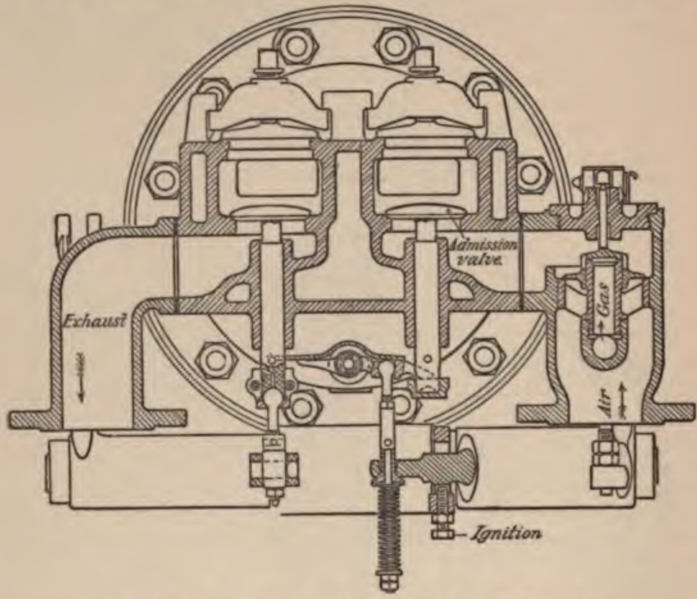


Fig. 82a.—Koerting Engine—End view, Valves, &c.

every revolution, instead of every other revolution. An arrangement has, therefore, been adopted with the exhaust valve eccentric, somewhat similar to that in the Lalbin engine. A toothed wheel revolves on the eccentric-rod, which is made hollow, and contains a smaller rod within it. By means of a rotating disc the inner rod is made to fit successively into the hollows, or rest against the teeth of the wheel, and the action is communicated to the eccentric at every other stroke. The other eccentric acts

as usual, but the charge is only ignited once in every two revolutions. Fig. 82 gives an elevation, and Fig. 82*a* an end view of this horizontal motor.

The Koerting-Lieckfeldt engines have been tested several times. Experiments were made in Germany by Professor Schöttler on one of the original type, with motor cylinder and pump. The engine was a 3 H.P. nominal, 2·18 B.H.P., and showed a consumption of 45 cubic feet of gas per B.H.P. per hour. The new type has yielded results as favourable as those obtained with any other compression engine. The most important tests were made in 1889 and 1890 by Professor Fischer. A 10 H.P. nominal engine gave a consumption of 23 cubic feet of gas per B.H.P. per hour, and the same figures were obtained with a 20 H.P. engine. Few gas engines up to the present time have worked more economically. A 1 H.P. engine tested at the Görlitz Exhibition in 1888 by Professor Levicki, of Dresden, consumed 34 cubic feet of gas per H.P. per hour. Details of these and of other experiments will be found in the table, p. 402. MM. Koerting have not been behind others in utilising Dowson gas, and three of their engines, with a total of 66 H.P. nominal, are driven by it at their works near Hanover.

**Adam.**—The Adam gas engine, constructed by the Maschinen-Bau Gesellschaft, at Munich, from the patents of Mr. G. Adam, resembles the last engine in many respects. Ignition is effected by propagation of flame; the governor acts on the exhaust valve, and the products of combustion are re-introduced into the cylinder instead of a fresh charge, if the speed is too great. The makers of the Adam, however, claim these details as the result of independent invention. Like the Koerting the engine is vertical. The smaller sizes are single cylinder; in the larger types two cylinders are used, as shown in Fig. 86.

The Adam is of the usual four-cycle single-acting type, and there is one working stroke for every two revolutions. Fig. 83 gives a sectional elevation of a single cylinder motor. The valves are worked in the same way as in the Koerting by a small auxiliary shaft $K_1$ driven from the crank shaft K by spur wheels two to one. The organs of admission, distribution, ignition, and exhaust are arranged side by side, and shown to the left in Fig. 83. Gas and air are admitted into the mixing chamber, the gas from above, the air from below. The admission valve is conical, and the stream of gas is directed into a chamber, where it is thoroughly mixed with the air. Another automatic valve then lifts to admit the mixture through the wide passage *b* at a certain pressure into the cylinder A with piston P. The constructors lay much stress on the width of the passage *b*, and the delivery of the gas and air at a pressure of several atmospheres into the cylinder. This pressure completes the thorough mixing of the charge, and the makers declare that,

without it, the high explosion pressures and consequent increase in work done on the piston cannot be obtained. If the charge is perfectly mixed, an ignition pressure of 10 to 18 atmospheres is possible. The gases, already compressed, being drawn into the cylinder by the up stroke of the piston, the next down stroke drives them into the ignition chamber H, where they are ignited and force up the piston; the second down stroke discharges the

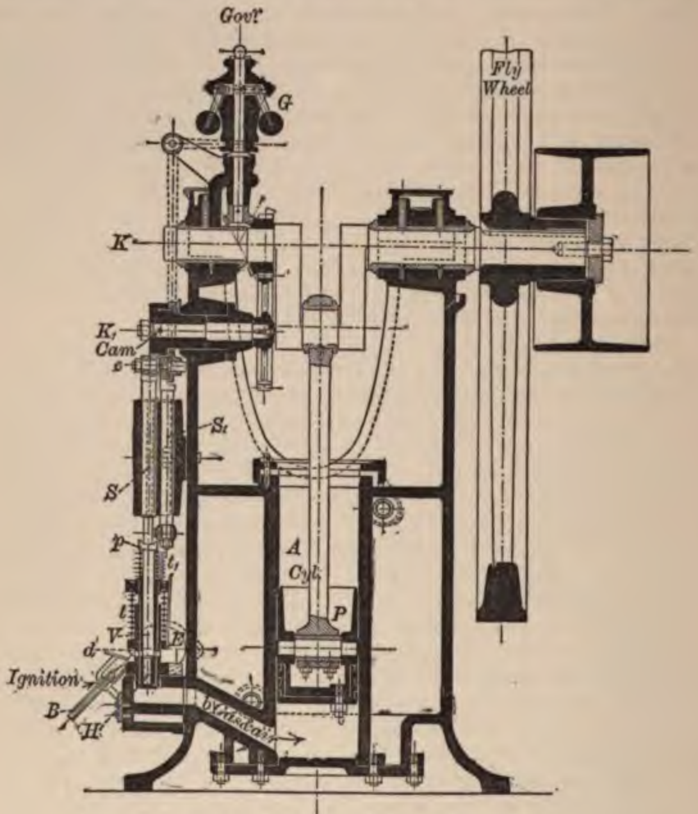


Fig. 83.—Adam Engine—Sectional Elevation.

products through the exhaust at E. The ignition-rod S and exhaust valve-rod $S_1$ are driven from the auxiliary shaft $K_1$, and are kept in position by springs $t$ and $t'$.

Although the principle of ignition by propagation of the flame has been applied to the Adam engine, the details are worked out in an original manner. The ignition chamber consists of a hollow

tube or cylindrical valve, V, enclosed within another in which works a small vertical piston, *p*. The bottom of the outer tube is pierced with holes passing through into the passage *b* and the compression space of the cylinder; the top is open, and communicates with an external flame B. At the moment of ignition, the compressed gases from the motor cylinder enter the tube through the passage *b* and the holes, while the small piston *p* is in its highest position. The down stroke of the motor piston drives them up the tube till they meet the flame at the opening *d*, and are ignited. The valve piston now descends, closes the opening *d*, thus shutting off communication between the flame B and the ignited gas in the tube, and drives down the cylindrical valve. A small orifice at the bottom, opening into the compression channel *b*, is thus uncovered, and the flame, cut off from upward progress, shoots through it into the remainder of the compressed gases, and rapidly ignites the whole (compare Fig. 80).

The speed is regulated by the ball governor, which keeps the exhaust valve open a shorter or longer time. The governor G, shown in Fig. 83, at the top of the engine, actuates the valve-rod $S_1$. The counter shaft $K_1$ carries two cams of different sizes for working the exhaust, and a hollow for the ignition valve. The two valve-rods end in a roller, *e*, just below the counter shaft. When the hollow in the cam is brought round to the rod S, working the small valve piston *p*, the rod is allowed to rise, and with it the piston, and the gases ignite. During the remainder of the revolution the rod and piston leave the hollow, and are driven down, and no ignition of the gases at the external flame B can take place. The exhaust valve-rod is usually opened once in every revolution of the counter shaft by the smaller cam. But if the speed be too great, the balls of the governor rise, and shift the roller *e* from the smaller to the larger cam. Thus the exhaust remains open during half a revolution of the shaft $K_1$, or while the piston makes one down stroke (exhaust), and the next up stroke (admission of the charge). Meanwhile the automatic admission valve cannot rise, being held in position by a strong spring. The suction of the piston failing to draw in a fresh mixture, the gases of combustion are re-admitted, and continue to enter till the speed is diminished, and the roller released and transferred to the smaller cam.

The constructors of the Adam have also introduced a twin-cylinder vertical engine for larger powers. A 25 H.P. motor of this kind was shown at the Munich Exhibition in 1888; and another of 30 nominal H.P., with four cylinders, at the Frankfort Electrical Exhibition in 1891. The latter was of the same type as the twin-cylinder engine, with double the number of cylinders. Fig. 84 gives a view showing a sectional elevation, Fig. 85 a plan, and Fig. 86 a section through one pair

of cylinders. The cylinders are placed diagonally to each other, and the makers consider this disposition advantageous; the centre of the axis of each is in line with the centre of the crank axis. The four pistons work opposite each other in pairs on to two cranks 180° apart, and one crank shaft; the up stroke of one of the pair of pistons is always more rapid than the corresponding down stroke of the other. Thus the engine, instead of being a four-cycle, is virtually a two-cycle motor, and there is an explosion beneath one piston of each pair, every time it passes the dead point. The valves for admission, ignition, and exhaust are the same as in the single-cylinder engine, and are ranged at

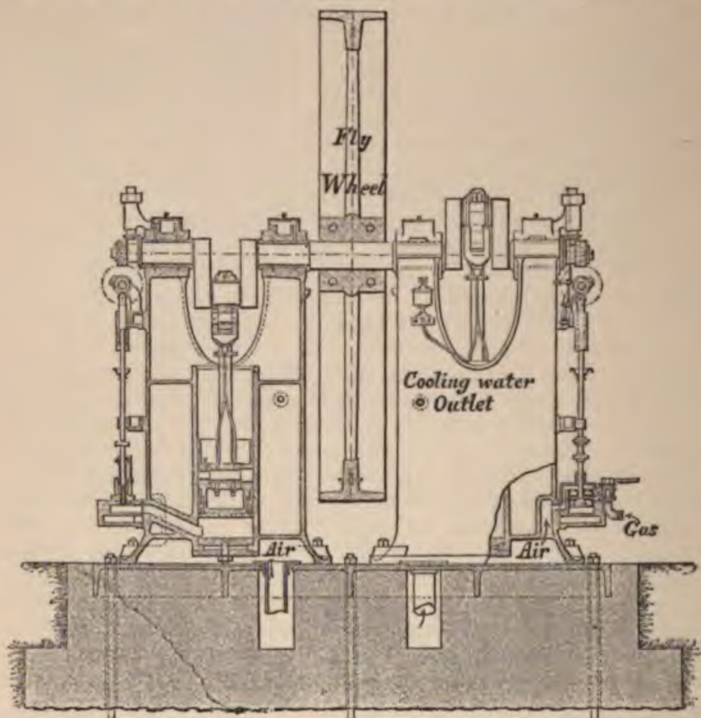


Fig. 84.—Adam Twin-Cylinder Engine—Side Elevation.

either end, at right angles to the cylinders. Figs. 84 and 85 show the arrangement of the parts; the flywheel is in the centre, with two cylinders on each side. The admission valve is automatic, the air enters from the base of the engine, through holes, into the seat of the valve, the gas from the side. The distribution valve, Fig. 84, is lifted from its seat at each stroke

of the piston, to admit the thoroughly mixed charge into the cylinder. On the left of the same drawing is shown the ignition valve and rod, and the method of firing the charge, which is similar to that in the single-cylinder engine. The ignition and exhaust valves are worked by rods from the small counter shaft; the latter runs at right angles to the crank shaft, from which it is driven by wheels geared in the usual way. The counter shaft carries cams, acting upon rollers, at the top of the exhaust and ignition valve-rods. There is a ball governor to each pair of cylinders, the action of which is the same as in the single-cylinder engine.

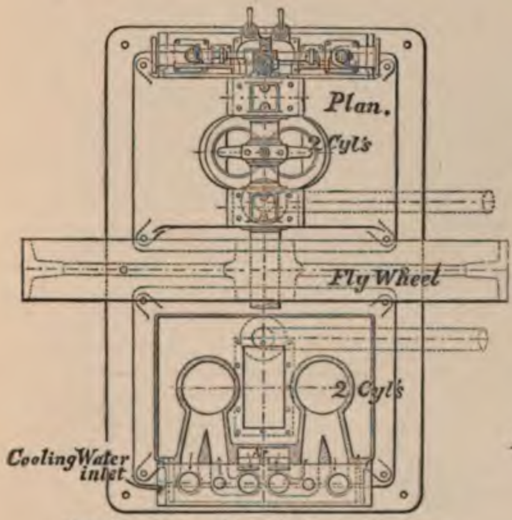


Fig. 85.—Adam Twin-Cylinder Engine.

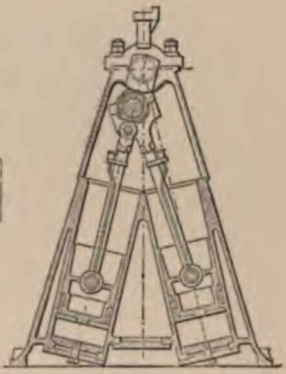

Fig. 86.

The most important trial made upon an Adam gas engine was carried out by Professor Schröter, of Munich, in 1889. The twin-cylinder engine tested was of 11 brake H.P., making 174 revolutions per minute, and showed a gas consumption of 31 cubic feet per B.H.P. per hour. Other and later experiments made upon different sizes of engine up to 12 H.P. gave better results. Details are given in the Table of Trials. The lowest consumption of gas was obtained at Nuremberg in 1888, where, with an engine of 11·72 B.H.P., the consumption was 27 cubic feet of gas per B.H.P. per hour, inclusive of the external flame.

**Benz.**—One of the most important and best designed of German engines is the Benz, patented in 1884, and constructed by the Rheinische Gas-Motoren Fabrik at Mannheim. In it the problem is again treated, how to obtain a motor impulse for

every revolution, without the additional complication of a second pump cylinder. The loss of power and want of regularity of four-cycle engines, giving an explosion only every two revolutions, is thus avoided. In the opinion of Professor Witz, the difficulty is more completely and satisfactorily solved in this than in any other engine. The chief novelty is the introduction of a charge of compressed air, to aid the piston, during its return stroke, in driving out the products of combustion. This arrangement is

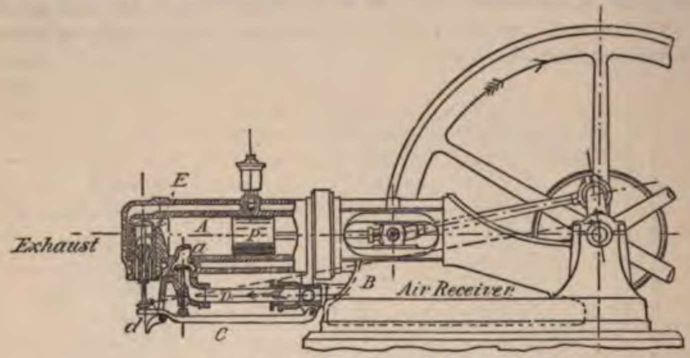


Fig. 87.--Benz Engine—Elevation.

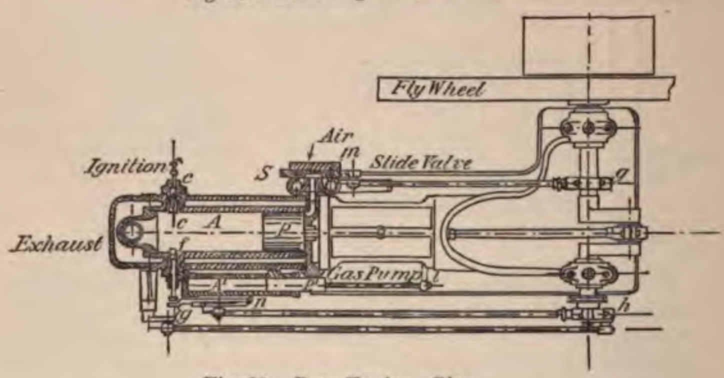


Fig. 88.—Benz Engine—Plan.

found to work well, but it entails a small pump to compress the gas, and a separate receiver, from which the compressed air is admitted into the cylinder.

Fig. 87 gives an elevation and Fig. 88 a plan of the Benz engine. A is the horizontal motor cylinder closed at both ends, in which the piston P works, $A_1$ the small gas pump with plunger piston $P_1$. The air receiver in the base of the engine B is shown at Fig. 87, and D is the pipe through which the

compressed air passes to the cylinder. S is a slide valve, worked by eccentric *g* on the crank shaft, through which and the port *m* the air is drawn, in the first instance, into the front part of the cylinder. During the next forward stroke, the side of the piston next the crank compresses it into the receiver below, from whence a charge of compressed air enters the back of the cylinder through D and the lift valve *a*. E is the exhaust valve, *c* the electric ignition wires. The two valves *a* and E are worked from the crank shaft by an oblique rod indicated by dotted lines in Fig. 87, a lever, C, and a small oscillating cam, *d*, which at a given moment pushes up the valves from their seat. The piston $P_1$ of the gas pump is fixed by a transverse bar, *l*, to the crosshead, and moves with it. The gas is admitted into the pump $A_1$ through a valve connected to the governor, which raises it for a longer or shorter time, according to the speed. The return stroke of the pump compresses the gas into the motor cylinder, through a passage and the lift valve *f*. This valve is held down on its seat by a spring, except at the end of the pump stroke, when it is pushed up by the projection *g*, acted upon by the lever *n* and eccentric *h* on the main shaft. For the compression of the air into the receiver the front part of the motor piston is utilised. Air is drawn in during the return stroke at the end of the cylinder nearest the crank, and compressed by the next forward stroke into the receiver, an arrangement which has been described in several other engines. This air is intended to act as a cushion in front of the piston, to keep the cylinder cool, and deaden the shock of explosion. The electric ignition is obtained from a small dynamo, and a Ruhmkorff coil. The mass of the engine is connected to the negative pole, the wires are insulated in a porcelain rod which projects into the cylinder at *c*, and contact between the points is established by levers working from the crank driving the exhaust and air injection valves.

**Benz Working Method.**—The action of the engine is as follows:—The piston being at its inner dead point, and the compressed charge behind it, ignition follows, and the piston is impelled forward. The gases expand doing work, and at the same time the air in front of the piston is compressed into the receiver, and the gas pump in its forward stroke draws in a charge of gas. Near the end of the forward stroke the exhaust valve is opened at E, and the pressure instantly falls. Shortly after, when the energy of the flywheel has carried the piston over the outer dead point, the air valve at *a* is lifted, and a charge of compressed air is admitted. The gases of combustion are driven out before it through E, and the cylinder so thoroughly cleansed, that, by the time the piston has passed through half its stroke, nothing but air is left, and the valves at *a* and E close. The piston now com-

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presses the air in front of it, and just before the end of the stroke the gas admission valve at *f* is raised, the gas and air, already compressed, mingle, and at the dead point the electric spark fires the charge. It should be noted that this cycle utilises the two sides of the piston, a constant pressure is maintained in the air chamber, and the indraught of fresh air certainly helps to keep the cylinder cool. The whole of the forward stroke being spent in expansion, and the discharge, admission, and compression of the gases being carried out during the return stroke, great expansion is obtained in proportion to compression. The action of the engine is ingenious, and it is said to work well, with great regularity of ignition, owing to the purity of the charge. As, however, the exhaust opens shortly before the completion of the expansion stroke, and the pressure in the cylinder is rapidly reduced, expansion must to a certain extent be checked, and the gases discharged at a comparatively high pressure and temperature. It is probably due to this, and to the number of the parts, that the engine, notwithstanding its excellent cycle, does not work with great economy.

**Trials.**—A series of experiments were made upon a 4 H.P. Benz engine at the Karlsruhe Exhibition in 1886. The mean number of revolutions when running full load on was 152, brake H.P. 5·61, and total consumption of gas per B.H.P. per hour 25 cubic feet. The proportional consumption was considerably higher when running empty. A gas consumption of 23 cubic feet per I.H.P. per hour has been claimed for it.

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## CHAPTER XIV.

## OTHER GERMAN ENGINES.



**Daimler.**—This engine is constructed by the Daimler Motoren Gesellschaft at Cannstadt, near Stuttgardt; the French makers are MM. Panhard and Levassor at Paris. One of these curious engines was shown at the Paris Exhibition of 1889. It has several novel and interesting features, the chief of which are its great speed, the absence of a water jacket, and the purity of the charge, due to the complete expulsion of the products of combustion. By employing high speeds, and thoroughly

cleansing the cylinder of the burnt gases, the inventor aimed at producing a light, but powerful engine. The original motor had one cylinder; the later type, as now made, is vertical with two cylinders. It was introduced in 1889, and is better designed and more economical than the first.

This Daimler motor differs from most others because all the organs, even the flywheel, are enclosed in an air-tight metal casing. This casing is intended to protect the parts from dust, to keep in the oil, and to serve as a reservoir, into which air is introduced and compressed by the action of the piston. The horizontal shaft is below, at right angles to the axis of the cylinders, and passes through the centre of the casing. There are two cylinders and two pistons, placed diagonally at a slight angle above the crank shaft, and working down through two connecting rods upon two cranks. The explosion in one cylinder is sufficient to drive both cranks through one revolution. The engine is of the four-cycle type, but the operations of admission, compression, explosion plus expansion, and exhaust are performed alternately in each cylinder. The gases are admitted during the down stroke of the one piston, and simultaneously expanded by the down stroke of the other, which is the working stroke. The next up stroke compresses the charge in one cylinder, and expels the burnt products in the other. Thus there is an explosion and a motor impulse in one or the other cylinder for each revolution, and a complete cycle is carried out in each cylinder during two revolutions. The charge is very rich, the products of combustion being completely expelled at each stroke. The flame spreads rapidly through the pure mixture, and the speed of propagation is even greater than the piston speed. These effects are obtained by means of two special air admission valves. One of these is in the centre of each piston, and is lifted by forks during the up stroke, closing when the pressure above is greater than that below. The other air valve is at the side of each cylinder, and opens automatically to admit air from without, as soon as the air in the reservoir has been exhausted through the piston valves. As this reservoir fills, the pistons descend, making their down stroke, and compressing the air below them. Having reached their lower dead point, they begin to return, the products of combustion being behind the one, and the fresh charge behind the other. At this moment the piston valves are lifted. In one cylinder the air from below mingles with the fresh charge, and is further compressed; in the other it drives out before it the products.

Figs. 89 and 90 show the arrangements of the parts. A and $A_1$ are the cylinders, P and $P_1$ the motor pistons, C and $C_1$ the two cranks, K is the crank shaft, and B the cylindrical casing in which the cranks are enclosed, resting on brackets; $c$ and $c_1$ are

the connecting-rods. At O, Fig. 89, is the automatic valve, opening to admit external air into the reservoir below the pistons. The two piston valves V and $V_1$ are lifted at each up stroke by two forks, I and $I_1$, to admit air from the base or reservoir into the upper part of the cylinder. The admission, ignition, and exhaust valves are enclosed in a valve chest, S, at the top of each cylinder. Admission is effected through an automatic valve, L, which rises as soon as the exhaust has closed and a vacuum is formed, and the gases pass to the cylinder through a

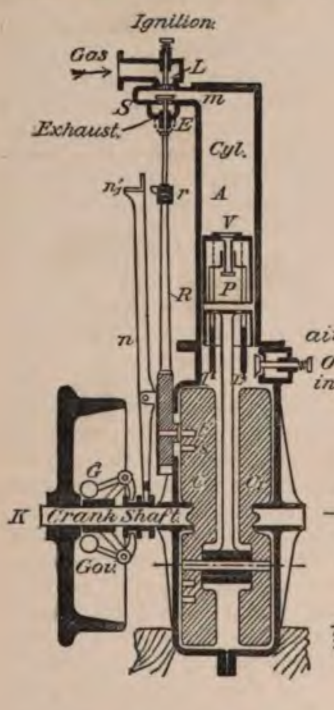


Fig. 89.—Daimler Engine—Section.

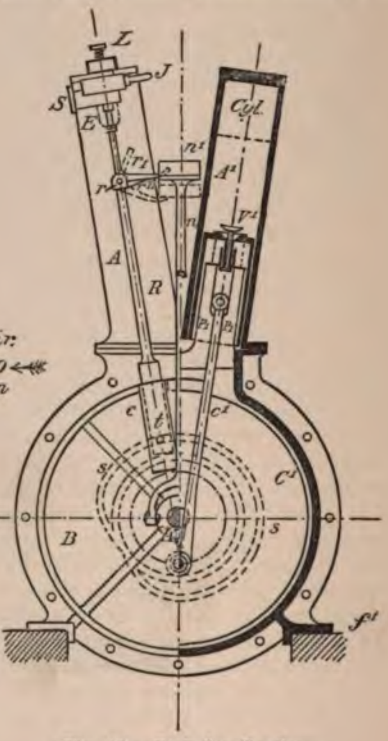


Fig. 90.—Daimler Engine—Elevation.

wide passage, *m*. In the next up compression stroke the mixture is driven into the hot ignition tube J and fired, and during the exhaust stroke the gases are discharged through the same passage, and through the exhaust valve E. In the admission and firing of the charge the engine does not differ much from others of the four-cycle type, but it has neither counter shaft nor eccentric. Admission and ignition are both automatically obtained by the

suction and compression of the piston, and the exhaust is opened by a vertical valve-rod, R, parallel to the cylinder.

As in most engines having an automatic admission valve, the speed in the Daimler is regulated by the governor acting on the exhaust valve, keeping it closed a longer or shorter time. As long as it is not opened, the pressure in the cylinder, increased by the compressed air from the reservoir, is sufficient to prevent the admission valve from rising, and admitting a fresh charge. The exhaust rod carries a lever with two arms, $r'$ and $r''$, oscillating round the fixed point $r$. A small projection, $t$, on the rod R fits into a groove, $s$, on the disc of one of the cranks, and as the crank rises it lifts the valve. This groove is so contrived that it only meets the projection on the valve-rod, and opens the exhaust, once in every two revolutions of the crank. Each time this occurs, the longer of the two arms reaches and opens the exhaust valve. If the speed exceeds the normal limits, the governor G on the crank shaft pushes up a second lever, $n$, terminating in a projection, $n_1$, Fig. 89. The projection catches in the arm $r_1$ of the lever, as seen in Fig. 90, and holds it down. The exhaust valve not being opened, the products of combustion remain in the cylinder, and no fresh charge is admitted until the speed is again reduced, and the arm of the lever released.

The speed of this engine is from 450 to 700 revolutions per minute, and for the power obtained it occupies a relatively small space. The 1 H.P. engine shown at the Paris Exhibition of 1889 made 700 revolutions per minute, and was 2 feet 5 inches in height. The cylinders have no water jackets. The charge of cool air introduced at every down stroke into each cylinder probably helps to prevent over heating. The Daimler has not hitherto been made for larger powers. For small motors, which generally consume more gas than larger, it is said by the makers to require about 35 cubic feet of gas per hour per I.H.P. It is a convenient little motor, light, and easily handled, and powerful for its size, on account of the great speed at which it runs. The casing in which it is enclosed, of course, conceals the parts. As they are not easily accessible, and the flywheel cannot be turned by hand to start the engine, a handle is fixed to the outside, to set it in motion. No trials on this engine appear to be on record.

**Dürkopp.**—The Dürkopp gas engine, made by the Bielefelder Nähmaschinen Fabrik, is another four-cycle vertical engine for small powers. The cylinder, and the admission, ignition, and exhaust valves are in the lower part of the engine, and the connecting-rod works upward on to the crank. The crank shaft is above, and carries on one side the flywheel and driving pulley. On the other is a vertical side shaft worked by wheels two to one. The valve chest is at the bottom, and all the valves are driven

by cams. Air and gas are admitted at the side, and pass into the mixing chamber through a valve lifted by a cam upon the side shaft. The same cam forces up a lever opening the exhaust. The gases of combustion are discharged through an exhaust valve made in two parts, larger and smaller. To obtain a more quiet discharge, part of the gases are allowed to escape through the smaller valve, before the main exhaust valve opens. Ignition is by a hot tube, the opening of which is uncovered by a cam lifting a small valve-rod. The governor is also placed on the counter shaft. The levers connected to the gas admission valve are opened by a cam once in every revolution of this shaft, but if the normal speed be exceeded, the balls of the governor rise, and shift the cam out of position. The gas valve remains closed, wholly or partially, until the speed is reduced, and the balls fall. No oil is said to be required for this engine, except for the crank shaft and piston-rod.

The engine is also made with two cylinders, side by side, working at the same angle on to the same crank shaft, and with two flywheels. For larger powers, up to 200 H.P., the makers have introduced a horizontal type, with one or two flywheels. The consumption of gas is said to be from 23 to 35 cubic feet per I.H.P. per hour, and the engine runs from 250 to 140 revolutions per minute, according to the size. In estimating the economical working of foreign engines by their consumption of gas, it must not be forgotten that the gas produced on the Continent has generally a lower calorific value than English gas.

**Dresdener Gas-Motor.**—The gas engine lately brought out by the Dresdener Gas-Motoren Fabrik (Hille's patent), is a compact and handy little vertical motor, single-acting, and using the Beau de Rochas cycle. Like many of the smaller engines which have appeared since the expiration of the Otto patent, it adheres very closely in working details to that type. It has the usual sequence of operations, admission, compression, explosion plus expansion, and exhaust, each occupying one forward or return stroke, and there is one explosion for every two revolutions. The piston-rod and connecting-rod work direct on to the crank shaft. A slide valve at the side of the engine, acted on by a valve-rod from a counter shaft, effects the admission of the gas and air and the hot tube ignition. The counter shaft is driven from the crank shaft in the usual way, by wheels, 2 to 1. The exhaust valve below the cylinder is opened by levers and closed by a spring, as in the Otto engine; it is worked from the counter shaft by a separate valve-rod. For small powers, from ½ to 6 H.P., these engines are made vertical, with a pendulum governor, and run at from 180 to 230 revolutions per minute. For powers from ½ to 30 H.P., a horizontal single-cylinder type, making 120 to 180 revolutions per minute, is used, with a centrifugal governor. Where great

regularity is required, as for electric lighting, the engines have two cylinders, are made in sizes from 3 to 60 Brake H.P., and run at a speed of 150 to 200 revolutions per minute.

**Kappel.**—The Maschinen Fabrik Kappel at Chemnitz, Saxony, have introduced a gas engine similar in many respects to the Otto. It is a single-cylinder horizontal engine, single acting, and is made for powers from 2 to 6 Brake H.P. The hot tube ignition is worked by a small slide valve; the admission of gas and air, and discharge of the exhaust gases are effected by ordinary lift valves. All these organs are driven from a counter shaft parallel to the crank shaft, and worked from it by wheels in the usual proportion. The speed is regulated by a spring governor. The engine runs at 170 revolutions per minute. By merely adjusting a screw, the number of revolutions can be greatly increased or diminished while the engine is running, which is sometimes desirable. The engine stands upon a strong cast-iron base, and is said to be noiseless in action. Another single cylinder type is made in sizes from 1 to 12 H.P. nominal, and runs at 140 to 180 revolutions per minute. The consumption of gas in both the Kappel and the Dresden-Hille engines, as given by the makers, is from 23 to 35 cubic feet per hour per H.P., according to the size of the engine. They do not appear to have been hitherto tested by experts.

**Lützky.**—The Nuremberg gas engine, designed on the Lützky system, is an interesting little motor, differing in several respects from the usual type. It is vertical, with the cylinder at the top, the piston working down through a connecting-rod upon the crank shaft, placed in a hollow conical base plate below. There are two flywheels, and the inventor asserts that the engine combines the stability of a horizontal, with the compactness of a vertical motor. The valve gear is reduced to a minimum, and there is neither counter shaft nor eccentric. Admission is by two automatic lift valves at the top of the cylinder. Through the first the gas passes into the mixing chamber, the second rises to admit the charge of gas and air into the cylinder, but the two are so connected by levers that the admission valve can fall, but cannot rise without raising the gas valve. The exhaust valve at the side of the cylinder is worked by levers and a cam on a small counter shaft, driven from the crank shaft by spur wheels, 2 to 1. The pressure of the gases prevents the gas admission valve from rising while the exhaust is open. The speed is regulated by a pendulum governor on the crank shaft, as in the Simplex engine. If the speed be normal, the lower heavier weight at the bottom of the pendulum is pushed outwards at every stroke by an eccentric on the shaft, and returning, releases the levers opening the exhaust from a notch on a disc, and the valve closes. But if the speed be too great, the pendulum weight does not strike against the eccentric in

time, the levers remain fixed in the notch, the exhaust is held open, and the gas admission valve cannot rise.

A 6 H.P. Lützky engine was tested by Professor Schöttler in Germany. When running without the governor at a mean speed of 200 revolutions per minute, the consumption of gas was 24 cubic feet per hour per H.P. When the governor was put on, the engine made 180 revolutions per minute, and the consumption at half power was 28 cubic feet per hour per H.P. The gas used was exceptionally rich. Good drawings of this engine will be found in the *Zeitschrift des Vereines Deutscher Ingénieure*, August 22, 1891. It is made in sizes from 1 to 10 Brake H.P., and runs at 180 revolutions per minute.

**Berliner Maschinen-Bau Motor.**—The gas engine made by the Berliner Maschinen-Bau Gesellschaft, in sizes from 1 to 30 B.H.P., is of the usual four-cycle horizontal Otto type, and stands on a strong foundation. Hot tube ignition is used, there are no slide valves, and the valves for admission and exhaust are worked by a counter shaft, at right angles to and driven from the crank shaft. A sensitive centrifugal governor regulates the quantity of gas automatically, according to the power required. The consumption is said to vary with the size of the engine from 23 to 35 cubic feet of gas per hour per I.H.P., and the average speed is from 200 to 160 revolutions per minute.

**Sombart.**—The Sombart engine, made by the firm of Buss, Sombart & Cie., of Magdeburg, and first exhibited in 1886, is one of the older motors, still retaining the original vertical type, and in which the charge is admitted and fired through a slide valve. In some respects it resembles the Adam and the Koerting, and the ordinary four-cycle is used. The admission and exhaust valves were formerly driven by spur wheels, 2 to 1, on the crank shaft; they are now worked by an eccentric on the same shaft. The gas and air are admitted through a slide valve acted on by a rod from this eccentric, the exhaust is opened from it by means of a roller and levers. Ignition is obtained in the same way as in the Wittig & Hees engine (see p. 64), by the propagation of an external flame through a passage in the slide valve. The pressure is equalised and the flame protected in a special manner, fully explained in the description of that engine. Fig. 91 gives a vertical section, and Fig. 92 a plan of the Sombart engine ignition, showing the covering over the internal flame, shaped like an extinguisher, and the small channel through which it is fed with compressed gas from the cylinder. The air enters through a trumpet-shaped opening, the mouth of which is closed and admission effected through holes round the circumference; by this arrangement the air is said to be drawn in noiselessly. The engine is controlled by an inertia governor, acting by the partial or total suppression of gas. In a trial by the makers, the consumption

of a 3·6 H.P. engine was 30 cubic feet of gas per H.P. per hour; the gas used was of poor quality.

MM. Buss and Sombart lay much stress upon two points, in the construction and working of their engine. In common with others who have given attention to the subject, they maintain that it is more advantageous to run a gas engine at a comparatively low speed, and that the gain in power, obtained by increasing the number of revolutions, is counterbalanced by the wear and tear, and the greater consumption of gas and oil. Few of their engines are intended to be driven at more than 150 revolutions per minute. They consider also that vertical engines give less piston friction, and are better in most respects than horizontal, and in this opinion most German makers of gas motors appear to concur. The Sombart engines are said to run with great

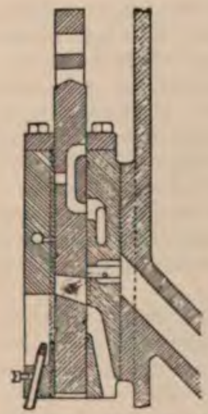

Fig. 91.—Sombart Engine Ignition Valve—Vertical Section.

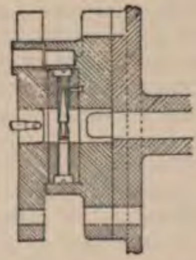

Fig. 92.—Sombart Engine Ignition Valve—Horizontal Section.

regularity, owing to the large size of the piston, and length of the connecting-rod in proportion to the stroke. They are made in sizes from 1 to 12 B.H.P., and run at 150 to 180 revolutions per minute. Drawings of the earlier type will be found in Schöttler, and of the modern type in Witz; in the latter hot tube ignition is used.

**Capitaine. (Theory.)**—Among engines recently introduced, an interesting and original little motor is the small vertical Capitaine. The inventor, Herr Emil Capitaine, is opposed in opinion to MM. Buss and Sombart, as regards the relative values of high and low speeds. In a paper communicated to the *Verein deutscher Ingénieure* (vol. xxxiv. of the *Zeitschrift*) he maintains that the greater the number of revolutions, the better results will be

obtained. At the same time he advances the novel point, that the piston speed may be quite different from, and independent of, the speed of expansion of the gases. Though usually classed together, the two are not synonymous, and their effect is by no means the same. If an engine be constructed, running at a certain speed, with a small diameter of cylinder and a long stroke, the speed of the piston will be considerable, and the speed of expansion relatively small. On the other hand, if another engine, going at the same speed, have a short stroke and a large diameter of cylinder, the piston speed will be relatively small, and the speed of expansion greater. Combustion, however, can never be instantaneous, and, therefore, the speed of the piston should be limited to the rate of combustion of the charge. The Otto engine owes its success partly to the carefully designed ratio between combustion and the speed at which the gases expand. To every speed of revolution in a gas engine, a certain rate of combustion corresponds. Hitherto attempts to increase the efficiency have been made by—1, More or less rapid combustion; 2, Raising the temperature of the cylinder walls; 3, More perfect expansion of the gases; 4, More complete expulsion of the products of combustion; 5, Greater compression. All these improvements, combined with a suitable rate of combustion, have yielded good experimental results. Herr Capitaine is himself of opinion that, to obtain greater economy in a gas engine, expansion ought to be more rapid, and explosion practically instantaneous; the diameter of the cylinder should be increased, and the stroke shortened.

The disadvantages of running at high speed are—1, More rapid wear and tear; 2, Uncertain ignition; 3, Incomplete combustion; and 4, Vibration. Against these drawbacks Herr Capitaine sets the gain of reduction in size and cost. If an engine can be made, without overheating, to run at twice as many revolutions per minute as another, its dimensions may be smaller, it will be lighter, less expensive, and the cost of transport smaller. Hitherto when engines have been tested at high speeds, no great gain in economy has been observed. Being constructed to run at a given number of revolutions per minute, and their ports proportioned to this speed, and to a given rate of combustion, they cannot be expected to work as efficiently, when they are driven at a much higher speed. The whole of the charge cannot reach the igniting chamber of the cylinder at the moment of explosion; part of it is ignited afterwards, and expands too late to act usefully on the piston. Herr Capitaine found, when testing an engine constructed to run at a high speed that, when making 320 revolutions per minute, an excellent indicator diagram was obtained. When the speed was increased to 800 revolutions, the efficiency was much lower, and diminished in proportion to the increase of speed. The number of revolutions should not

be in excess either of the speed of propagation of the flame, or the development of pressure in the gas.*

**Capitaine Engine.**—In the Capitaine the piston speed is the same as in other motors, but the number of revolutions, or speed of expansion of the gases, is doubled. Another distinctive feature claimed for this engine is that, by an ingenious arrangement of the admission port, the incoming charge is kept apart from the products of combustion, and not allowed to mingle with them. The engine is of the single-acting vertical type; a sectional elevation is shown at Fig. 93. The disposition of the valves and working parts is similar to that of the Lützky engine. The cylinder A is at the top, and the piston P works down upon the crank shaft K, which, with the flywheel, is below. Gas and air are admitted from above through a double-seated automatic lift valve. The air enters at D and passes down into the wide port through the bottom of the valve at *c*, the gas through the upper seat of the valve at *f*. The top and bottom of the valve are connected by a spring, *s*, and work independently. Before passing through *c* into the cylinder, the gas and air mingle in the annular chamber formed by the valve, which imparts to them a circular motion of considerable velocity. They next impinge against a projection, *g*, and the wide diameter of the port checks their velocity, and forces them to enter the cylinder in a steady stream. This is the method also employed to prevent the fresh charge from mixing with the gases of combustion, which are discharged through the exhaust port at the side E.

The piston having drawn in the charge, the up compression stroke drives it into the hot ignition tube B. This tube is made of porcelain, which is said to afford more resistance than any other substance to the heat and the high pressure, and is more easily kept at an equal temperature. In its passage through the admission port, a portion of the incoming charge is directed at once into the ignition chamber. As there is no timing valve the gases enter freely, and the mixture is supposed to ignite more readily because part of it is already in contact with the hot ignition tube. The exhaust valve E is driven by a rod from an eccentric, H, on the crank shaft. Above the termination of this rod is a hollow lever, into which the projecting end of the exhaust spindle fits at every revolution. But it is only at every other revolution that a second lever is interposed between them, and the eccentric, pushing up both levers, reaches and opens the exhaust valve.

The ordinary four-cycle is used in this engine. The centrifugal governor G is on the crank shaft, and acts through a

* See on the subject of speed in Gas Engines the summary of Dr. Slaby's experiments, in Appendix, p. 389.

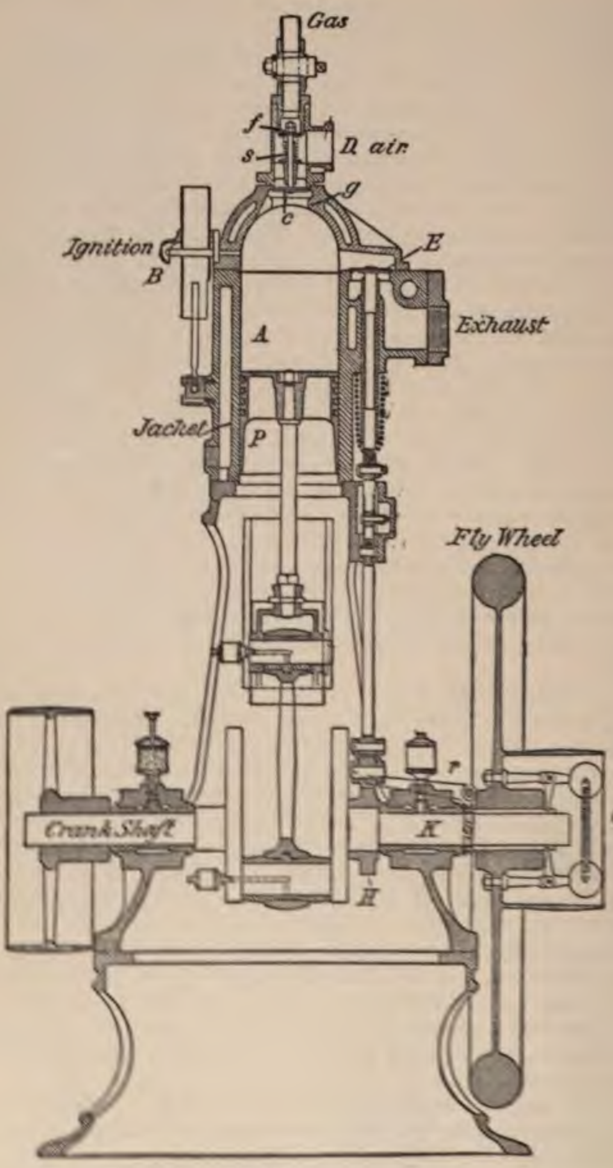


Fig. 93.—Capitaine Engine—Sectional Elevation.

rod, *r*, and a catch on the lever opening the exhaust. If the speed be too great the balls rise and draw the rod outwards. The knife edge of the lever misses the catch, the exhaust valve remains open, and no fresh charge can enter the cylinder, till the speed is again reduced within normal limits. All the wearing parts in this motor are carefully designed, wide and large. It is one of the newest engines, and has not yet been tested by experts. The inventor claims a considerable economy in the consumption of gas. In a trial on a 3·36 B.H.P. engine, with a cylinder diameter of 6·6 inches, and 6·4 inches stroke, and making 300 revolutions per minute, 27·4 cubic feet of gas were used per B.H.P. per hour. The usual speed of the engine is 360 revolutions per minute.

The makers have introduced a special water tank, for use where there is a difficulty in obtaining a sufficient supply for the jacket. The water circulates continually from the tank to the jacket of the cylinder and back again, and it is kept cool by a small fan. The engine was exhibited at the Crystal Palace Electric Exhibition, 1892, by the English Capitaine Manufacturing Company. A motor of the same type has been introduced for working with petroleum, and is described in Part II.

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## CHAPTER XV.

## GAS PRODUCTION FOR MOTIVE POWER.

CONTENTS.—Gaseous Fuel—Natural Gas—Coal Gas—Distillation—Combustion—Bischof's System for Generating Gas—Thomas and Laurent—Kirkham—Siemens—Pascal—Tessié du Motay—Strong—Lowe—Wilson—Lencauchez—Dowson.

THE first attempts to produce gas from coal were made as an experiment to obtain light, without any intention of utilising it as a motive force. The process of extraction was too costly for the gas to be employed to drive the motors invented at the beginning of the century, and many were the devices described by the patentees, to obtain a suitable explosive gas. In one of the earliest gas engines, brought out by Street in 1794, he proposed to generate a gas to act on a piston by sprinkling a few drops of petroleum or turpentine on the bottom of a cylinder kept at a red heat. The liquid was evaporated, exploded, and drove up the piston. Barber obtained gas for driving his engine by heating coal, wood, &c., in a retort, according to the method now practised in gas works. The process of making gas was in its infancy, carried out only in large towns and cities, and

there was much prejudice against it. It was also very dear. Practically in those days there was no gas to be had, and it was impossible to produce it cheaply, for driving small motors.

**Gaseous Fuel.**—As a fuel, however, coal gas was used long before its advantages as a motive force were perceived. During the first half of the century, as soon as the great value of steam was recognised, the economical use of coal became an important question. Without fuel, steam could not be generated, but although this is still usually done by burning coal under a boiler, it has long been known that it is rather wasteful. It is difficult by direct combustion to obtain temperatures as high as when gases previously extracted from the fuel are burnt. For chemical purposes, where great heat is required, gaseous fuel has been in use for many years. Cheap gas, made in producers or generators, is now extensively employed in the manufacture of iron and steel, and other metallurgical processes, as being better and cheaper than burning the coal itself. A fresh stimulus was given to its production as soon as gas engines began to attract public notice and favour. It was seen that the maximum economy in driving them could never be attained, as long as they were worked with town gas, and inventors have for twenty years laboured to produce a cheaper and equally efficient gas.

There are many ways of extracting gas from fuel. The composition of different gases will be found in Chapter XVII., and it is only necessary here to mention, without going into details, the different methods by which it is obtained. These consist in bringing together, with or without combustion, the chemical constituents of the coal and air, carbon, oxygen, hydrogen and their compounds. If the hot fuel is moistened with water or steam, the quantity of hydrogen is increased; if air be introduced, a much greater amount of oxygen is added. In either case the carbon in the fuel unites with the oxygen of the air or of the water, and more carbonic oxide and carbonic acid are produced, than when the gas is formed from the chemical elements contained in the coal only. If the fuel is burnt in a closed vessel, and steam added and evaporated, the gas produced is richer in hydrogen than if air is admitted. When air is introduced, the same process takes place, but instead of hydrogen being liberated, there is a large residuum of inert and useless nitrogen.

Gaseous fuel may be divided into four classes, namely: I. Natural gas. II. Oil gas, obtained from petroleum, vegetable oil and refuse, shale, fat, resin, &c. III. Carburetted air, or air saturated with volatile spirit. IV. Gas extracted from coal, wood, peat, and other varieties of fuel, either by distillation, or with the addition of air or water. In the latter case it is called poor or water gas, or producer gas. We will now proceed to consider generally these four methods of gas making.

I. **Natural Gas.**—The process of generating gas from coal, or from the vegetable substance which forms the basis of coal, is carried on by Nature as well as by man, though on an infinitely larger and slower scale. The gas is produced by the heat of the earth and the slow combustion of chemical decomposition. Gases exhaled from swamps and commonly known as "will o' the wisp" or marsh gas, are only a variety of lighting gas, which when artificially produced contains about 40 per cent. of marsh gas. As the decaying vegetation of swamps, bogs, and forests undergoes further decomposition or slow combustion, a fresh layer of soil is formed over it, and it passes very gradually during ages of time through the stages of peat, lignite, brown coal, and eventually to coal. Time, the earth's heat, decomposition and oxidation, and pressure, frequently cause the escape into the atmosphere of the gases thus generated. Of this the disastrous explosions in mines afford an example. Marsh gas or carbonic oxide (usually termed "fire damp" or "choke damp") distilled, so to speak, from coal, and at a high pressure, are liberated by excavation, and rush into the mine workings, often with fatal consequences. Where the gases find a natural outlet at the surface through fissures in the ground, as in many places in North America, and in Russia along the shores of the Caspian Sea, they are given off from the earth harmlessly. This natural gas, consisting almost entirely of marsh gas, is of excellent quality for lighting and heating purposes, and contains more caloric than artificially made gas. Formerly it was allowed to escape to waste, but it is now partially utilised, and furnishes the greater part of the lighting gas used in several towns of the United States.

II. and III. The methods of producing gas from oil, and of charging air with petroleum spirit (carburetted air), will be described in the second part of this work.

IV. **Coal Gas.**—The gas used for lighting and heating is extracted from coal in two ways, either by—

1. Distillation, or the application of external heat to the coal.
2. Combustion, or actual ignition of the coal.

Distillation produces a much richer gas, and is the process universally used in gas works. The cheaper and inferior kinds of gas, such as water or producer gas, are obtained from combustion. These are employed as fuel instead of coal, and to drive gas engines. Professor Witz draws a further distinction between hot and cold distillation; the latter is chiefly employed for carburetted air.

1. **Distillation of Coal.**—The earliest method of obtaining gas from coal, first practised by Murdoch, was to heat the coal in closed retorts and distil the gas from it. By this process the gases are given off, leaving a residuum of coke, &c. As the air is carefully excluded, the distilled products contain no gases

except those already in the coal. Roughly speaking, two-thirds of the constituents are hydrogen, carbon, and their combinations. It is only of late years, since gas motors have been made for larger powers, that the need of a cheap substitute for this distilled or town gas has been felt. As long as it was required only for illumination, the quantity used by each consumer was too small, to make economy of production an important question. As far as the heating value of town gas is concerned, it is well suited for driving a motor, but it is unnecessarily pure for this purpose, and the price per 1,000 cubic feet is relatively great. To produce town gas separately for driving small motors is, of course, impracticable, on account of the cost of production, &c. For some time, therefore, much attention has been paid to the production of a cheaper gas, less pure, but not liable to deposit carbon in the passages and ports of a motor.

2. **Combustion of Coal.**—The second method of manufacturing gas is by burning the coal, and three processes are employed, each producing a different kind of gas. In all of them, ordinary atmospheric air is required to assist combustion.

In the first process a forced air blast is used. The gases are rapidly generated by driving a current of air through the glowing coal, and combustion is thus stimulated. This furnishes what is called producer gas, and sometimes Siemens' gas, because it was first introduced by Sir William Siemens, as a fuel and substitute for solid coal. This gas is often used for heating purposes, but is not rich enough to drive a gas motor.

The next kind is known as water gas. Here the method followed is also to burn the coal, and when it is in a state of incandescence, a jet of steam is injected into it. The steam is decomposed into oxygen and hydrogen, which recombine with the gases from the coal. The carbon present unites with the oxygen, and forms carbonic oxide and carbonic acid. A very rich gas is thus produced, which contains a larger percentage of the heat in the coal than gas made on any other system. Water gas is much used in America as fuel, instead of ordinary coal, because anthracite, from which it is made, is cheap and abundant. One disadvantage of this method is that the gas cannot be continuously produced. The blast of steam lowers the temperature of the coal, and, after an interval of about ten minutes, there is not enough heat to cause decomposition and recombination of the chemical elements forming the gas. The process of injection is then stopped for a time, and air instead of steam introduced to revive combustion. As a rule, water gas and producer gas are made alternately in the same apparatus.

The third system is a combination of the two preceding methods. Instead of alternately injecting steam and air into the mass of incandescent fuel, both are admitted together. The

jet of steam carries with it, into the fuel, a current of air duly proportioned, and the gas, though poorer in quality, can be made continuously. Hitherto there have only been two applications of this system known to the author. About sixteen years ago it was first brought out and patented in England by Mr. J. Emerson Dowson, and the value of Dowson gas for driving motors is now fully recognised. About the year 1887 another method was introduced in France by M. Lencauchez. These three last kinds of gas are chiefly made from anthracite or coke. If ordinary coal is used, the tar, ammonia, and other residual products impoverish the gas, and are rather difficult to get rid of. Another characteristic of these cheap gases is that they contain a much larger quantity of carbonic oxide than town gas. Carbonic oxide is highly poisonous, but has no smell, and care is needed in using it, to prevent any escape.

**Bischof.**—The earliest attempts to obtain gas for heating purposes from the combustion of coal, instead of from distillation, were made by Bischof in 1839. Peat fuel was burnt in a brick chamber, air at atmospheric pressure was admitted from below, through holes in the covering of the ashpit, and the gases generated during combustion were drawn off through a chimney and damper from the top of the furnace chamber. In 1840 Ebelmen made a furnace for generating gases, worked by a blast of air, and a much larger quantity of gas was produced by this means than in Bischof's apparatus.

**Thomas and Laurent.**—But the merit of being the first to design a practical gas producer belongs to MM. Thomas and Laurent, who, between 1838 and 1841, constructed a gas generating furnace, in which many modern improvements were anticipated. Air compressed by a blower was admitted at the bottom of a furnace, and the decomposition of the air was assisted by the injection of superheated steam, in the proportion by weight of 35 of air to 1 of steam. The height of the generator was sufficient to cause all the oxygen of the air to be transformed into carbonic oxide. The fuel used was charcoal, wood, peat, coke, and anthracite.

**Kirkham.**—Another remarkable apparatus was brought out in 1852 by Messrs. Kirkham, who, working independently but on the same lines as Thomas and Laurent, produced their gas by the direct combustion of the fuel in a furnace, instead of by applying external heat to the coal, and distilling the gas from it. They were the first to use what is called the "intermittent" system of gas making—that is, the alternate admission of steam and air to the coal. The fuel being kindled in the generator, a blast of air was turned into it, until combustion was thoroughly established; the air was then shut off, and steam was injected and quickly decomposed by the heat. After a short time the admission of steam was stopped, and air again introduced to revive

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combustion. Other gas producers were brought out by Ekmann in Sweden about 1845, Beaufumé in France in 1856, and Benson in 1869. In most of these early efforts, the object was not so much to generate lighting or heating gas from coal, as to utilise the waste gases from furnaces.

**Siemens.**—Several important gas producers were introduced with successive improvements by Sir W. Siemens, who gave his attention to the subject as early as 1861. His main object was to produce a gas which could be used as a substitute for ordinary fuel in furnaces, and he was the first to bring the question of gaseous fuel prominently forward. In his producer a very slow draught of air and slow rate of combustion are employed, and the gases are cooled as they leave the generator. His designs have since been perfected, and the Siemens' improved gas generator is now largely used for all sorts of metallurgical and manufacturing purposes. The two forms of gas producers introduced into France by Minary in 1868, and his later recent apparatus were invented with the same object, of replacing solid fuel in furnaces. A useful little generator was brought out by Dr. Kidd in 1875, intended to provide a cheap gas for domestic use and cooking. With the exception of the Siemens' apparatus these were all on a small scale, and none of them were originally intended to generate gas for working motors.

**Pascal.**—Pascal in 1861 was the first to develop the ideas of Thomas and Laurent, and those of Kirkham, and to test practically a system for manufacturing cheap gas, by the addition of steam and air to the incandescent fuel. Except in its application, his method differed little from theirs. A cylindrical gas generator filled with coal was surrounded by a boiler with which it communicated. The coal was fired, and steam from the boiler admitted alternately with air from a blower, worked by the motor. Pascal's system of making gas has long been discontinued.

**Tessié du Motay.**—Another method brought out by M. Tessié du Motay in 1871 is still used in America, in the Municipal Gas Works, New York. A brick furnace, enclosed in a wrought-iron cylindrical shell, is charged with fuel from above, and the gas drawn off through an annular space at the top. Air is introduced through a blast pipe running across the centre of the furnace, and the ashes and clinker are discharged below. This is said to be one of the best of the intermittent gas producers, and is simple and efficient.

These different generators exhibit the successive steps in the production of gas from coal. The first improvement on the process of distillation was the substitution of internal for external combustion. Instead of the outward application of heat, the fuel was burnt in the furnace, and the gas led off from it in pipes. A blast of air was next introduced, to accelerate the production of

gas; the last and perhaps the most important innovation was the addition of a jet of steam. This water gas has been applied with good results to drive a 6 H.P. Otto engine. In a trial extending over several days it was found that the working cost was four-tenths of a penny per H.P. per hour, and in other respects the engine worked satisfactorily. More gas was used than when coal gas was employed, but the price of generating it was much lower. The comparative economy of the two gases, taking the mean cost of production in both cases, was 0·84 of a penny per H.P. per hour when driving the engine with coal gas, and 0·25 of a penny with water gas.

**Cheap Gas.**—The great cost of working the Lenoir engine gave a fresh stimulus to the production of cheap gas. About 1862 two systems were proposed on the Continent for making water and generator gas. In the first, designed by M. Trébouillet, retorts filled with charcoal were brought to a red heat, and superheated steam forced through them. Charcoal was also used in the other method, invented by M. Arbos of Barcelona. The generator was in two divisions. The upper part contained water, and formed a kind of boiler and superheater. The steam mixed with air was admitted at the bottom of the furnace. Neither system was applicable to the Lenoir engine, which required about 100 cubic feet of gas with a calorific value of 21,978 B.T.U. (British Thermal units) per H.P. per hour.

**Strong.**—Two systems, the Strong and the Lowe, for making cheap gas by admitting steam and air intermittently into burning

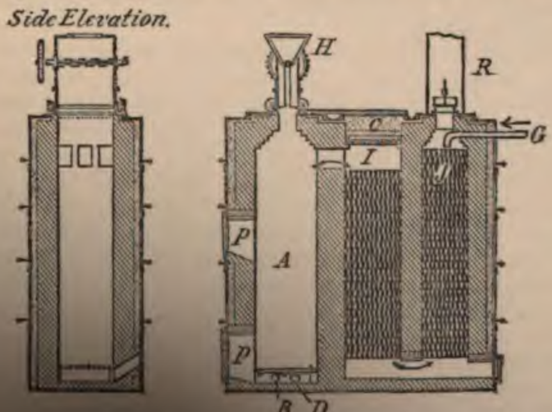


Fig. 94.—Strong Gas Producer.

fuel, were introduced about 1874. Both are of American origin, and are now c[illegible]l, especially in America and Germany. Fig. 94 gives [illegible]ratus, and shows the

method of generating and purifying the gas, and superheating the steam before it enters the furnace. A is the generator filled with anthracite or coke, charged through the hopper H above, or through the doors *p*, *p*. I and J are the heating chambers, loosely stacked with fire bricks. A forced blast of air enters at B below the furnace, and another current is admitted at C. As soon as the coal is kindled in A the air blast from B causes active combustion, and the gases generated are driven into the first chamber I. Meeting here the draught of air from C they are forced down through the fire bricks, and up in the direction of the arrows through the second chamber J till they reach the reservoir R. As soon as the fuel in the furnace A, and the bricks in the chambers I and J are at a red heat, the air is shut off from the blast pipe B, and the opening C, and steam introduced at G passes through the chambers and the furnace in the reverse direction to the air. In its passage through the red-hot fire brick it becomes superheated. At the top of the furnace finely-powdered fuel is sprinkled into the steam. Brought in contact with this coal dust continuously fed from the hopper by means of a slow moving Archimedean screw, the steam instantly separates into its elements, and these combine with the carbon to form rich water gas, which is drawn off at D. After a few minutes combustion slackens, and the process is reversed. The steam is shut off, the forced blast of air again admitted, and producer gas given off. The Strong gas is specially adapted for heating. It is perhaps the best of the producers working on the intermittent system, and generating gas alternately from air and from steam.

**Lowe.**—The Lowe process resembles the Strong in several respects, and contains a generator and a single superheating chamber; in the latter the gases given off during combustion are heated, instead of the steam. The producer is worked intermittently. By the side of the iron cased brick generator furnace is a superheating chamber filled with loose bricks, a reservoir of water, and a scrubber for purifying the gases. The generator being charged with anthracite, combustion is started by a blast of air. The hot gases given off rise to the top of the generator, and are conveyed through a pipe to the lower part of the superheater, where a fresh current of air is admitted, kindling the gases, and causing the flames to rise through the loosely stacked bricks. As soon as the bricks and the coals in the generator are at a red heat, the air is shut off and superheated steam blown into the furnace. A small stream of petroleum drops from above on to the glowing fuel, and as the gases produced by the decomposition of the steam pass upwards through the generator, the volatilised oil mixes with them and forms hydrocarbons. The gases next pass through the superheating chamber, which being always maintained at a

constant heat, the composition of the gases is always uniform. They are then purified by passing through the water tank and the scrubbing chamber filled with wet coke. The gas produced by the Lowe system differs is some respects from others, and the inventor asserts that the quality does not vary.

**Wilson.** — The Wilson gas producer, like those already described, was not originally intended to generate gas for driving a motor, but if the furnace be fired with anthracite or coke, and the gases well washed, they can be used for that purpose. The method of introducing the steam is novel. It enters under pressure through a narrow tapering nozzle, and carries with it a strong current of air in the proportion of 20 parts of air by weight to 1 of steam. In order that the whole of the air and steam may perfectly combine with the fuel, they are delivered into the centre of the glowing coal. Before they are carried off, the hot gases from the furnace are led into a chamber round the upper part of the producer, where the coal is fed in from a hopper. The fresh fuel is heated before combustion by these gases, and the chamber acts almost in the same way as a retort. The producer has also an automatic arrangement for carrying off the ashes and clinker.

Many other systems for making gas have been patented, and some are now at work. Among these are generators by Grobe and Lürmann for steel furnaces, Sutherland for welding metals, Young and Beilby for extracting ammonia from gas. All, however, are outside the present subject, as they have not hitherto been used to furnish gas for driving engines. Up to the present time only two apparatus have been designed and worked with the special object of generating gas continuously for motive power, the Dowson in England, and the Lencauchez in France.

**Lencauchez.**—The Lencauchez system for making gas is of recent date, and the English patent (No. 4798) was taken out March 17, 1891. It was invented by M. Lencauchez, and the apparatus first made at the Chantiers de la Buire, Lyons, and called the Buire-Lencauchez system. In outward appearance the generator differs little from the Lowe, but the gas is continuously produced. It has now been adopted by MM. Delamare-Deboutteville and Malandin, the makers of the Simplex engine, and they have added a Buire-Lencauchez gas producer to many of their latest motors, from 16 to 100 H.P.

Fig. 95 shows a sectional elevation of the apparatus, attached to a Simplex gas engine. A is the furnace or generator with fire-brick lining K, between which and the outer iron casing is a layer of sand L. C is the grate, B the scrubber filled with coke, from whence the purified gases pass through Y to the gas holder. The fuel is automatically charged through a hopper, M N, above the furnace; the ashes are withdrawn once in twenty-four hours through the door F. A current of air, previously heated by the

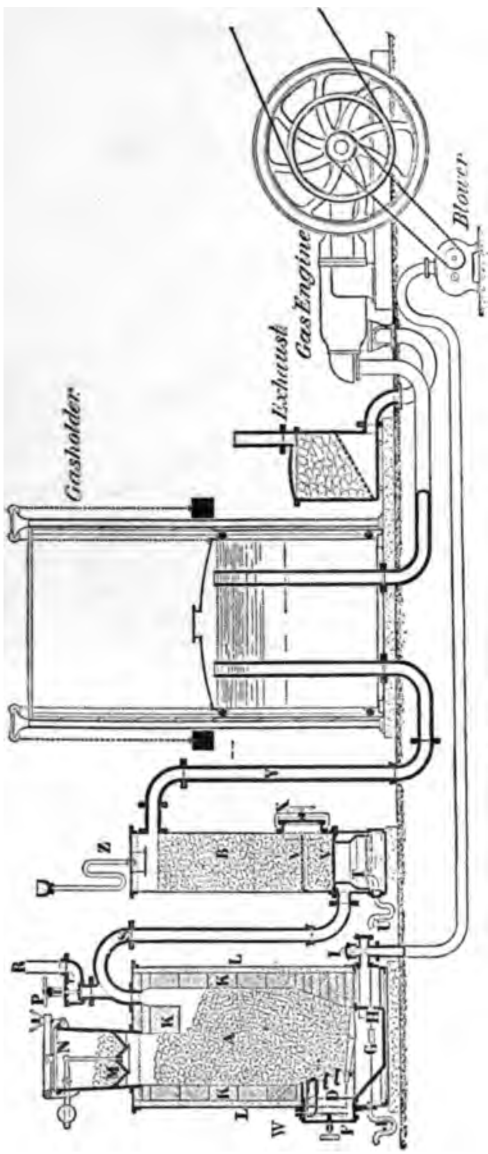


Fig. 95.—Lencauchez Gas Producer—Sectional Elevation.

furnace, enters the generator at H from a fan or blower worked by the engine, and is driven into the closed pan G. By a

cock at W a small stream of water, preferably drawn from the jacket of the gas engine, is admitted into a hollow trough E, and falling through the bars D D on to the grate is there evaporated, and mixes with the blast of compressed air. The two pass together into the furnace, and the surplus water is carried off at J. The gases are then led off from the top of the furnace by the pipe S into the scrubber or purifier B filled with coke, upon which water from the siphon Z is continually playing through a perforated cone or distributor. V V are the grate bars, X the door for withdrawing and changing the coke. On their way to the scrubber the gases pass the hydraulic joint T, which is intended to prevent the return of any gas to the furnace. The water dripping through the coke is carried off at U. The gases are next delivered sometimes to a distributing chamber, sometimes direct to the gas holder. If not required for driving the engine, they are allowed to escape into the atmosphere by a chimney. By an ingenious arrangement the furnace can be shut off for a few minutes, the injection of air and steam suspended, and the engine driven by gas from the holder while the grate is cleaned, an operation only necessary once in twenty-four hours. The holder contains sufficient gas for starting the engine. The production of gas is regulated by a valve I (through which the compressed air passes to the furnace), and which is attached by a chain to the top of the gas holder. As soon as the holder is filled, the valve I is automatically raised, and the air is not allowed to enter the furnace until the contents of the holder have been reduced.

**Advantages—Consumption.**—The special advantages of the Buire-Lencauchez gas producer are its economy of heat and its simplicity, no boiler being required. Both the air and water are usually heated before they enter the furnace, and heat is thus utilised. This producer can also be used to generate gas from cheap and poor coal, whereas most others require anthracite or coke. MM. Delamare and Malandin no longer find it necessary to burn English anthracite in their Lencauchez generators, but inferior non-bituminous French coal, which is much cheaper. Hence the system is specially adapted for use where best coal is difficult to procure. French anthracite has neither the same calorific value, nor is it as pure as English. Gas made on the Lencauchez system with English anthracite has a heating value of 174 B.T.U. per cubic foot at ordinary temperature and pressure; when cheap French anthracite coal is used, its heating value is 152 B.T.U. per cubic foot. With large motors driven by Lencauchez gas the consumption of fuel is about 1·3 lb. of good anthracite per H.P. per hour. A 50 H.P. Simplex engine has been working continuously with this gas since 1888 at M. Barataud's Mills at Marseilles. It is said to require a consumption of only 1·2 lb. English anthracite per B.H.P. per hour.

In a paper published in the "Procès Verbaux de la Société des Ingénieurs Civils," October, 1891, details are given by M. Lencauchez of the economy which can be realised by using large gas engines driven by cheap gas, made in special generators. A good gas plant, burning the commonest fuel, transforms more than 80 per cent. of the solid combustible into gas, while the best steam boilers, according to M. Lencauchez, seldom utilise more than 70 to 75 per cent. of the heat contained in the coal. The thermal efficiency of the gas engine being usually reckoned at double that of the steam engine, a total economy of about 50 per cent. of fuel may, the writer considers, be obtained by using poor gas instead of steam.

**Dowson.**—It is to Mr. J. Emerson Dowson that the merit belongs of having fairly inaugurated the process by which steam and air are admitted to a furnace together. The gas obtained is much poorer than water gas, but richer than producer gas; it can be rapidly and continuously generated, and with the proper admixture of air is very well adapted for driving gas engines; it is not intended to be used for any other purpose. It possesses the further advantage of being much cheaper than lighting gas. Before its introduction, it was considered impossible to work gas engines as economically as steam engines of about the same power. With few exceptions only small motors were made, and owing to the expense of town gas, it was supposed that large power gas engines could never compete successfully with steam. The adoption of Dowson gas has shown that it is possible to work a 100 H.P. engine with much greater economy than a good 100 H.P. steam engine, and a still more economical consumption of fuel has been obtained with an engine indicating 170 H.P. From this point of view, the services rendered by Mr. Dowson, in making it possible to produce power more cheaply by the use of his gas, are very great. It is now employed in a large number of motors, and although the cost of driving them has already been much reduced, the inventor is of opinion that "still better results can and will be obtained when an engine is really designed to give the best effect with this gas."

Fig. 96 shows an external view of a complete Dowson gas plant. To start production, nothing is required except anthracite or coke to fill the generator, and a little water to evaporate into steam for injection into the fuel. The steam pressure varies from 30 to 50 lbs. per square inch, according to the size of the gas plant to be served. The wrought-iron generator is seen in the front to the left of the drawing, and the small vertical boiler for producing the steam stands beside it to the right. The boiler has a closed grate, and a small serpentine coil of steam pipe above the fire. In this hot coil the steam is superheated, before it passes through the pipe above the boiler to the lower

part of the generator. Midway between the two is an injector, through which a current of air is forced into the generator by the velocity of the steam. The cylindrical generator is lined with fire brick, and the fuel is fed in through the hopper above. The gases generated by the combustion of the anthracite or coke combine with the oxygen derived from the decomposition of the steam and air, and are conveyed through a return valve and pipe

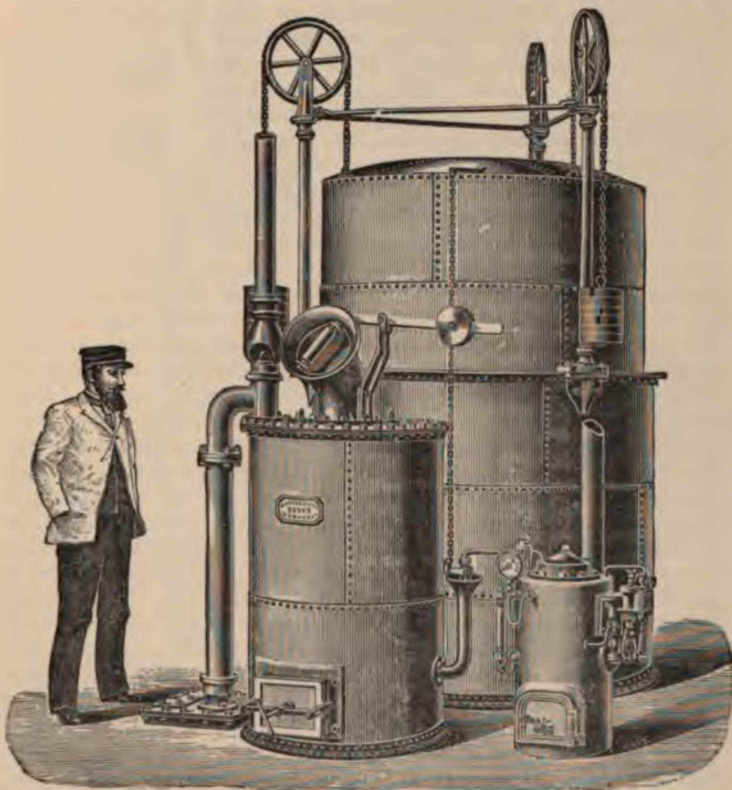

Fig. 96.—Dowson Gas Plant.

into the hydraulic box, shown at the extreme left of the drawing, under the floor. This box is divided into two parts and half filled with water. The gases passing through the water are washed, and another pipe conveys them to the scrubbers, usually placed inside the gas holder, to economise space. One is the wet scrubber, the coke in which is continually moistened by water sprays; in the other dry coke is loosely stacked. From here the

part of the generator. Midway between the two is an injector, through which a current of air is forced into the generator by the velocity of the steam. The cylindrical generator is lined with fire brick, and the fuel is fed in through the hopper above. The gases generated by the combustion of the anthracite or coke combine with the oxygen derived from the decomposition of the steam and air, and are conveyed through a return valve and pipe

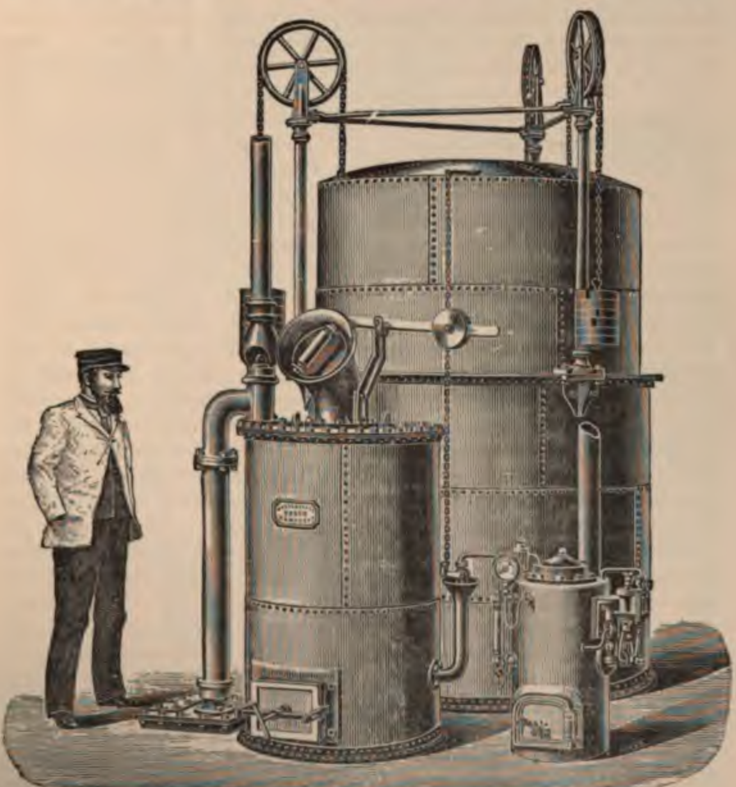

Fig. 96.—Dowson Gas Plant.

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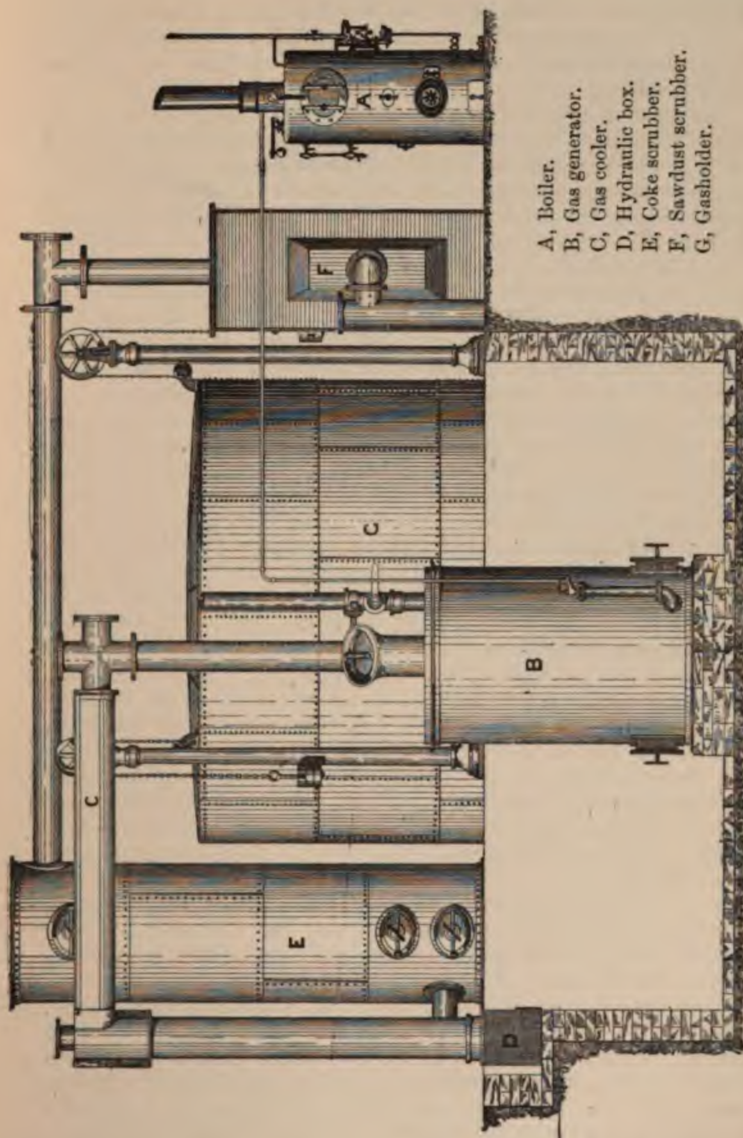
partially purified gases enter the holder, and are thence conveyed to the engine, passing on their way through receivers containing sawdust, to cleanse them further.

To regulate automatically the production of gas, the following method is adopted:—The top of the holder is connected to a chain attached to the air injector, and seen in the drawing. If too much gas is generated, the holder rises, lifts this chain, and raises a valve from which the air and steam are allowed to escape, instead of entering the generator. As soon as production is reduced, the holder sinks, and the valve is released. At Fig. 97 is shown a Dowson gas plant at the flour mills of Messrs. Mead & Sons, Chelsea. The arrangement differs slightly from that already described, because the plant is larger, and the scrubbers are outside the gas holder, but the system is the same; the different parts are indicated by letters. The trial made with this producer is mentioned at the end of the chapter, p. 205.

A large number of experiments have been undertaken with Dowson gas, and have proved its economy, and the relatively small cost of using it to drive engines. To make a proper comparison between a steam-engine plant and a Dowson gas plant and motor, the cost of the fuel should in both cases be given, and the generator considered as forming part of the gas engine, in the same way as a boiler forms part of a steam plant. In England the gas can be produced at a cost of about 2d. to 3d. per 1,000 cubic feet, according to the quantity required, but in the case of large works, where a steam boiler already exists, the consumption of fuel can be reduced, by utilising this steam for the generator. It should, however, be remembered that the gas contains about 55 per cent. of nitrogen and carbonic acid, as against about 8 per cent. of nitrogen in gas manufactured by the Strong process, but besides being continuously generated, Dowson gas has a higher calorific value than producer gas. It is about four times less rich in heating value than town gas, and requires a corresponding diminution in the quantity of air used to dilute it in the cylinder of an engine. The actual charge admitted into a gas engine is no larger than with town gas, because this ratio of air is much smaller. Instead of from 5 to 14 parts of air to 1 of gas, Dowson gas needs only from 1 to 1½, and 4 volumes of this gas are equal in heat to 1 of coal gas. The exact proportions of heating value of average coal gas as compared with Dowson are 3·8 to 1.

Difficulties were at first found on using it with the Otto engine, because the products of combustion were retained in the cylinder; but these have now been overcome. With the Simplex engine it gives excellent results, because the initial compression is greater, and the cylinder more completely cleansed before each explosion. Dowson gas can only be made with coke or anthracite, but both are easily obtained in England. It is yearly becoming



A, Boiler.
B, Gas generator.
C, Gas cooler.
D, Hydraulic box.
E, Coke scrubber.
F, Sawdust scrubber.
G, Gasholder.

Fig. 97.—Dowson Gas Plant at Mead's Flour Mills, Chelsea.

more widely known, and generally used. It is easily produced, the plant is compact and simple, takes up little space, and

requires little attention; it does not burn with a smoky flame, and deposits no impurities in the ports and valves of an engine. It can be made continuously, rapidly, and at a much lower cost than town gas.

**Experiments.**—Trials with Dowson gas will be found in the table at p. 404. Three types of engine have hitherto been tested with it, the Simplex, the Otto, and the Atkinson. The Simplex, engine was twice carefully experimented on by Professor Witz with Dowson gas. On the first occasion the engine indicated 8·10 H.P., and the consumption of gas per B.H.P. per hour was 86·8 cubic feet. In 1890 M. Witz tested the 100 H.P. Simplex engine, shown at the Paris Exhibition, and found the consumption 1·34 lb. English anthracite per Brake H.P. per hour. Experiments made by MM. Teichmann and Böcking in 1887 on a 30 H.P. nominal Otto engine gave a consumption of 103 cubic feet of gas per I.H.P., equivalent to 1·67 lb. of fuel per B.H.P., per hour. With an engine indicating 18 H.P. at Messrs. Crossley's works, the normal consumption of Dowson gas during a working day is 81·7 cubic feet per I.H.P. per hour, or about four times as much as lighting gas. Dowson gas is now used to drive all the engines at Messrs. Crossley's works, and it furnishes a total of from 250 to 300 H.P. A good test of economy is found in the average working expenses throughout the year of large engines driven with this gas. At Messrs. Spicer & Co.'s Paper Mills at Godalming the total I.H.P. is 400. In all the engines Dowson gas is used, and the average consumption during 20 weeks, including waste, was 1 lb. fuel per I.H.P. per hour. The same results per I.H.P. have been obtained at the Crossley works during 35 weeks, with all their engines. In MM. Koerting's extensive engineering works near Hanover there are three engines, two of 25 H.P., and one of 16 H.P. driven by Dowson gas. At the Severn Tweed Co.'s Mills at Newtown two trials, each extending over six days, were made upon four Crossley engines, driven with Dowson gas, and indicating a total of about 280 H.P. In the first trial anthracite was used, and the total consumption was 1·23 lb. per B.H.P. per hour. During the second the generator was fired with coke, and 1·73 lb. per B.H.P. per hour was used. The average cost of fuel in each case was about the same per H.P.

Two careful and important tests have recently been made, to test the economy obtained with Dowson gas. The first by Mr. J. Tomlinson was on a 15 nominal H.P. Atkinson Cycle engine, used to pump water from a well at the Uxbridge Waterworks. The well was 100 feet deep, and the water had to be pumped into a reservoir a mile and a half away. The engine was coupled direct to double-acting pumps 80 feet below the surface, and was driven at 86 revolutions per minute. The total quantity of fuel used was 1·06 lb. per I.H.P. per hour, or 1·48 lb.

per water horse-power per hour, and about 16·4 per cent. of the units of heat in the fuel were converted into total work, or 12 per cent. into water power. The other trial was made in February, 1892, on a 16 H.P. nominal Crossley-Otto engine, using Dowson gas. The trial was conducted by Mr. Dowson himself, and gave results considerably more economical than any obtained with smaller engines. It is of special interest, because it was made on the largest engine yet driven with Dowson gas. The maximum I.H.P. was 173·6—B.H.P. 147·6, but the engine did not run at full power, and the mean I.H.P. developed was 118·7. The fuel consumed during the trial was 0·76 lb. per H.P. per hour, including the anthracite in the generator, and the coke in the boiler, but allowance was made for getting up steam. This trial was at Messrs. Mead & Co.'s Flour Mills, Chelsea.

A large Dowson gas producing plant, capable of making gas for 200 indicated horse-power, has lately been erected at Messrs. Tangye's Works, Birmingham. The generator is fired with anthracite or coke, and the gas is produced at a cost of 3d. per 1000 cubic feet, equal to coal gas at, say, one shilling per 1000 cubic feet.

The following table (taken from A. Naumann's Paper on "The Transformation of Heat into Permanent Chemical Energy" *) gives the heat produced by the combustion of various gases :—

TABLE OF THE HEAT OF COMBUSTION OF GASES.

| Heating Gas. | Heat of Combustion of 1 litre Gas, the Water produced being assumed to be gaseous at 15° C. |
|---|---|
| Producer Gas, | 1044 calories. |
| Carbonic Acid Producer Gas, | 1739 ,, |
| Water Producer Gas, from liquid water at 15°, | 1652 ,, |
| Water Producer Gas, from gaseous water at 15°, | 1790 ,, |
| Water Gas, | 2812 ,, |

[1 litre = 61·025 cubic inches = 0·0353 cubic foot.]

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## CHAPTER XVI.

## THE THEORY OF THE GAS ENGINE.

CONTENTS.—Laws of Gases—Boyle's Law—Gay-Lussac's Law—Joule's Law of the Mechanical Equivalent of Heat—Thermal Units—Specific Heat —Carnot's Law—Perfect Cycle—Isothermal and Adiabatic Curves— Ideal Efficiency—Other Cycles—Indicator Diagrams—Movements of Heat in a Cylinder.

**Laws of Gases.**—No complete study of the gas engine is possible, unless it includes a knowledge, however slight, of the gas

* *Berichte der deutschen chemischen Gesellschaft*, 25, 1892, pp. 556-62.

itself, or working fluid, the physical and chemical laws governing it, and the chief phenomena taking place in the cylinder of an engine. None of these phenomena are the result of chance. The laws controlling the action of gases have been accurately determined. The force of the explosion of gas in a cylinder seems, at first sight, impossible to regulate. But it can now be defined with precision, and is always exactly proportioned to the pressure and temperature of the gas when admitted, and the amount of its dilution with air. Thus, if a certain weight of gas, composed of known chemical elements in a definite combination, and diluted with a given proportion of air, be admitted into a cylinder of known dimensions, its action can be accurately foretold, and the work estimated which it is able to do.

The term "working fluid" is applied to the medium of heat in thermal motors. It is equally correct to call it the "working agent," and the latter expression will here be used. No absolutely perfect gas is at present known, that is, a gas which obeys perfectly the theoretical laws, and cannot be condensed into a liquid by any change of temperature. But in the case of coal gas, air, or oil, the chief agents for the transmission of heat in internal combustion engines, the variation from a perfect gas is so slight that, for practical purposes, it may be neglected.

Of the different laws regulating the action of gases, two only are essential, in order to understand the phenomena in a heat engine. The first is known as Boyle's Law in England, and Mariotte's Law on the Continent. It was first propounded by Robert Boyle in 1662, and is as follows:—

**Boyle's Law.**—I. If the temperature of a gas be kept constant, its pressure or elastic force will vary inversely as the volume it occupies.

This proposition defines the relation between the three attributes invariably found in all gases, whatever their composition —temperature, volume, and pressure. The word temperature denotes the condition of a body as regards sensible heat; volume is expressed in cubic feet, and the specific volume of a gas is the number of cubic feet it occupies per lb.; pressure is the elastic force the gas exerts upon the walls surrounding it, reckoned in lbs. per square inch. All the phenomena taking place in a heat engine are produced by varying one or other, or all three of these attributes,—that is, by increasing or diminishing the temperature, the volume, or the pressure of a gas. Boyle's law may be illustrated by imagining a cylinder containing a piston, both perfectly tight. The piston is set half-way through the length of the cylinder, and gas admitted on one side of it; and the temperature of the gas being kept constant, the supply is next cut off. If the piston be then moved to its farthest limit, it will uncover the other half of the cylinder, and the available volume will be doubled. The gas will instantly ex-

pand, following the piston, and as no more is admitted, the same quantity will occupy twice as much space as before. But this increase in volume of gas will also be accompanied by a corresponding diminution in pressure. The force exerted by the gas on the piston will, at the end of the stroke, be half as much as before. If the space originally occupied by the gas be called one volume, and its pressure be taken as equal to that of the atmosphere, or in round numbers, a pressure of 15 lbs. on every square inch of the piston surface, the gas, when the piston has moved to the end of the cylinder, will occupy two volumes, but will exert a pressure of only $7\frac{1}{2}$ lbs. per square inch upon the piston. The temperature being always the same, the products of the pressure and the volume will remain constant. To express Boyle's law differently—

$$\text{Volume} \times \text{pressure} = \text{constant.}$$

Now let us suppose that the temperature be at the same time varied; quite different conditions are immediately introduced, and the law no longer applies. If heat be furnished to the cylinder described, and the temperature of the gas raised, without allowing the piston to move out, the gas will continue to occupy the same space as before, but the increase of temperature will cause the pressure to increase. The heat will force the particles of gas further apart, and the pressure or tension will rise until, if the temperature be continually increased without an increase in the volume, the gas will burst the cylinder. This expansion of gas through the application of heat, and its corresponding contraction when heat is withdrawn, has been carefully verified, and the degree of variation in volume or pressure, determined by experiment, has been found to be in exact proportion to the quantity of heat added to, or abstracted from, the gas. It forms the basis of the following second law of gases, called Charles' law in England, and the law of Gay-Lussac on the Continent.

**Gay-Lussac's Law.**—II. The pressure or the volume of a gas being maintained constant, all gases expand $\frac{1}{273}$ part of their volume, or increase in pressure $\frac{1}{273}$ part for every rise of 1° C. in their temperature. The law may be stated differently thus:—

Suppose a gas is at constant volume in a closed vessel, and exerting a pressure of 273 lbs. per square inch. For each degree Centigrade added to its temperature, the pressure of the gas will increase 1 lb. per square inch. If, therefore, its temperature be raised 10° the pressure will be 283 lbs. per square inch. The converse of the law also holds good. All gases contract in volume, or lose $\frac{1}{273}$ part of their elastic force, for each degree Centigrade by which their temperature is lowered. Therefore, if a gas at 0° C. be reduced 1°, it will contract by $\frac{1}{273}$ part of its volume, and if it were possible to continue the process, and to abstract

gradually 273° C. of heat from the gas, a point in temperature would be reached, called the "absolute zero," at which the gas would possess neither volume nor pressure. This limit of the "absolute zero" is not a theoretical point, but definitely fixed by natural laws, and it is impossible to pass beyond it. According to the law of Gay-Lussac, more heat could not be abstracted, even if the lowest limit of temperature were not reached, because the gas would have no further power of contraction, and therefore of diminution in pressure.

No one has yet been able to reduce a body to this extreme of cold, although in recent experiments it has been approached. The "absolute zero"—viz., 273° below 0° C. and 460° below 0° F.—is, however, the basis of all calculations of temperature in scientific work. The zeros fixed by Fahrenheit, Réaumur, and Celsius are all arbitrary determinations, below which temperatures continually fall, but they cannot be used as the original starting point for measuring heat.* In calculating the heat in an engine, the temperatures are usually measured from the absolute zero, or ordinary temperature Centigrade + 273°. Now in the first law of gases there are only two characteristics of a gas and their variations to be considered. In the second law, a third is added, and the relation between the three is expressed thus:—

$$\frac{v \times p}{T} = \text{Ratio or R.}$$

Put into words this formula runs:—The volume $v$ multiplied by the pressure $p$ of any gas, and divided by the absolute temperature T, are equal to a certain fixed ratio, R. The same law may, of course, be expressed thus:—

$$v \times p = R \times T.$$

The value of R for air is 29·64 units C.

This expansion of a gas $\frac{1}{273}$ of its volume for every degree Centigrade added to its temperature, is equal to the fraction 0·00367, called the coefficient of expansion. The term "coefficient" signifies a fixed quantity or mean value, accurately determined by experiment, and applying equally to all bodies possessing the same properties, and under the same conditions. If the amount of heat added to any gas be known, the degree to which it will expand can be exactly calculated by this coefficient. As it increases in pressure or expands in regular proportion to the heat added, it is evident that there must exist some fixed relation between the expansion of the gas, and the tem-

* The centigrade scale fixed by Celsius has been practically adopted in Europe and America for scientific work. It is used in this book, in order not to confuse the student passing on to other and more elaborate theoretical works, in which he will find no other temperature given.

perature producing it. This relation forms a link between the laws of gases we have just been considering, and those governing the action of heat, and furnishes a good example of the first and most important Law of Thermodynamics, the Mechanical Equivalent of Heat. It may be briefly stated thus :—

**Joule's Law—Mechanical Equivalent.**—I. Whenever heat is imparted to, or withdrawn from a body, energy is generated in proportion, or an equivalent amount of mechanical work is done by the body, or upon it by external agency. The proportion between the heat absorbed, or given out, and the work performed is always the same.

This law, which has given a new direction to scientific thought during the last half century, was fore-shadowed by Count Rumford and Sir Humphrey Davy, and discovered almost simultaneously in England by Joule, in Germany by Mayer, and in France by Hirn. The priority is usually ascribed to Joule, who published the results of his accurate experiments in 1843, and the law is known in England as the Law of the Mechanical Equivalent of heat, or briefly as Joule's Equivalent. It is twofold in its operation and effects, and may be expressed as :—Heat is a form of energy, or Mechanical energy (work) may be converted into heat according to a definite law.

To explain it we will again use our illustration of a cylinder with an air-tight piston, containing a given volume of gas. As long as the temperature of the gas does not vary, its volume and pressure have been proved to stand to each other in exactly inverse ratios. As the one increases, the other decreases. If heat be added, the gas expands, the pressure rising in exact proportion to the increase in heat. It is the law of the mechanical equivalent which explains the reason of this increase in expansive power. Heat has been put into the gas, and disappears as heat, to reappear in some other form. Nor can it be otherwise. The Law of the mechanical equivalent is a necessary deduction from the principle that nothing in nature can be lost or wasted. All the heat imparted to the gas must be found again, either as heat, or transformed into some other form of energy. In the case of our cylinder and piston, all the heat will be changed into work, and will be absorbed in producing the expansive force of the gases driving out the piston. Were there no piston, and the cylinder open at one end, work, since it must be done by the expansion of the gases, would be done on the atmosphere. In no case can the heat imparted to the gas be lost. Either it is represented by the expansion of the gas, or carried off by radiation to the conducting substances surrounding the cylinder.

The earliest and simplest example of heat transformed into mechanical energy is shown by a cannon, which is really a primitive form of heat engine. The bore of the cannon repre-

sents a cylinder, the bullet is acted upon in the same way as a piston. A solid combustible is used to produce inflammable gas, but the effect is the same as in a gas motor. Heat applied to this combustible or powder causes it to explode, and the force of the explosion, or expansion of the gases generated, drives out the bullet with great velocity. Not only can heat be thus transformed into actual work, but the converse proposition that energy may be translated into heat, has been demonstrated by many careful experiments. Both are mutually convertible forces, and this may be verified by suddenly arresting the progress of the bullet. The energy of motion imparted to it by the heat of combustion and not yet expended, is immediately retransformed into heat, and the bullet is found to be much hotter, than if it had been allowed to continue its course till its velocity was spent. Sir Humphrey Davy demonstrated the truth of this proposition in another way, by his celebrated experiment of rubbing two pieces of ice together in a vacuum, without change of temperature. Water was produced, showing that the ice was partially melted, and the heat required to effect this change of state could only have been obtained by friction,—that is, by mechanical energy or work, as no heat had been added externally to the ice.

The theory of the Mechanical Equivalent is equally applicable, whether a gas be heated or cooled. If heat be imparted to it, and the gas allowed to expand, the particles are driven further apart, if heat be abstracted they shrink. Work will be done *on* the gas by contraction, instead of *by* the gas through expansion. But if a gas be compressed at constant temperature, and no heat abstracted, work being done on it, and the gas caused to diminish in volume, heat will be stored up, and the temperature of the gas raised. The energy of motion or mechanical work of compression of the particles is transformed into heat. If, however, the heat is carried off in proportion as it is evolved by contraction, the gas will, as has been shown, gradually decrease in volume, in temperature, and in pressure, until the point of absolute zero is reached. In this way the law of the Mechanical Equivalent confirms the existence of an absolute zero. If it were possible for the gas to exceed this limit in any one of its three characteristics, the fundamental law of thermodynamics would be violated. If it could decrease still further in volume, work would be done in contraction without any corresponding diminution in temperature, and we should have energy without heat. The two aspects of the law in its application to gases are, expansion by the addition of heat, and contraction by the withdrawal of heat. In a heat motor the first is called positive, and the second negative work. It is with the heat produced by external work, that the theory and practice of engines is chiefly concerned.

**Thermal Units.**—The proportion between the heat added and work done being a fixed quantity, it is possible to determine accurately the work theoretically performed for a given amount of heat supplied. The two are linked together in practice, and the relation in which they stand to each other is expressed in the following way :—In England it is usual to reckon that one unit of Heat or British Thermal Unit (B.T.U.) raises 1 lb. water 1° Fahr., and if this unit of heat be applied to a body, it is equivalent to the work of lifting 772 lbs. 1 foot in height, or a weight of 1 lb. a distance of 772 feet. On the Continent the unit of heat is called a "*calorie*." One *calorie* raises the temperature of 1 kilogramme of water 1° C., and if this quantity of heat be converted into work, it will lift 425 kilos. through 1 metre, or 1 kilo. through 425 metres. The unit of measurement of work is called foot-pound in England (ft. × lb.), and a kilogrammetre abroad (kilo. × metre). The difference lies only in the respective units of weight, and temperature employed here and on the Continent.

The measurement of the exact proportions between heat and work was determined by James Prescott Joule, after long and careful experiments. The apparatus he principally made use of to verify the law of the mechanical equivalent consisted of a closed copper vessel filled with water. Within it were revolving paddles attached to a vertical spindle. The spindle and paddles were made to rotate by means of a cord passing over a pulley connected to a weight. When the weight fell, the spindle rotated, causing the paddles to revolve and to agitate the water, and heat was produced by friction between them. The rise in degrees of temperature of the water was found to be exactly in proportion to the distance in feet passed through by the weight, multiplied by the number of lbs. it weighed. From these and many similar experiments with water and gases, Joule deduced his great law.

**Specific Heat.**—All bodies have not the same capacity for absorbing heat. Those which are heated without changing their physical state require less heat to raise their temperature than bodies which are converted, during the rise, say from liquid to gaseous. A large quantity of heat must, for instance, be imparted to water, because, after it has absorbed a certain amount of heat it ceases to be a liquid, and becomes a gas, steam. Specific heat is the quantity of heat necessary to vary the temperature of any body through one degree, the quantity of heat required to raise or lower the temperature of an equal weight of water through one degree being taken as the unit. Water is universally adopted as the standard of comparison, and its specific heat being greater than that of most other bodies, their specific heats are expressed in fractions. For example, a heat unit represents the amount of heat required to raise 1 lb. of water 1° F., there-

fore, 100 heat units will raise its temperature 100° F. The specific heat of mercury is ·03332. To raise 1 lb. of mercury through 100° F. will require ·03332 × 100° × 1 lb. = 3·332 heat units. The specific heat of mercury is, therefore, about $\frac{1}{30}$ that of the same weight of water, which requires thirty times more heat units to bring it to the same temperature. Specific heat has been ably illustrated by Mr. H. Graham Harris under the similitude of "appetite."*

Further, the specific heat of the same body will vary according to circumstances. If the body remains under stationary conditions, its specific heat will be less than if its condition changes. To return again to the cylinder containing a given volume of gas. As long as the gas remains inert or passive, and its volume does not vary, it possesses a definite specific heat, which being known, the quantity of heat to be added, to raise it to a certain temperature, can be calculated. But if the piston is driven out, by reason of the expansion of the gas which, according to Gay-Lussac's law, increases in volume by $\frac{1}{273}$ for every degree rise in temperature, work will be done, and heat will in consequence be expended. More heat will, therefore, be required to heat the gas—that is, its "heat appetite" will be greater when it has forced out the piston than before. Under the first condition, the heat absorbed by the gas is defined as its "specific heat at constant volume," because, the piston being stationary, neither the volume of the cylinder nor that of the gas has varied. As the piston moves towards the end of the stroke, the volume is increased, and expansion takes place. The heat of the gas is then called its "specific heat at constant pressure," because, while the volume of the cylinder has varied, the pressure over the piston area has been constant. Therefore the specific heat of the gas at constant pressure will be higher than at constant volume, and the proportion between the two represents the work done by the gas. That is to say, the increase of specific heat in the gas denotes the amount of heat required to maintain the requisite pressure on the piston, and, therefore, the work it has performed.

The ratio between these two specific heats is of great importance, and has frequently to be employed in calculations of efficiency or mechanical energy in a heat engine. It varies slightly as given by different authorities, but is usually reckoned at 1·39 by foreign, and 1·408 by English writers. The following table, taken from Regnault, Grashof, Ayrton and Perry, and others, gives the specific heats of various gases at constant pressure and constant volume, and their ratio:—

* See Mr. Harris's Cantor Lectures on "Heat Engines other than Steam," delivered before the Society of Arts, May, 1889, to which the student is referred for an exceedingly clear elementary treatment of the subject.

TABLE OF SPECIFIC HEATS OF GASES (from various Authorities).

| | Specific Heat at Constant Volume. | Specific Heat at Constant Pressure. | Ratio. |
|---|---|---|---|
| Air at ordinary temperature, . . | 0·168 | 0·237 | 1·41 |
| Dry air (Rankine's constant), . . | 0·169 | 0·238 | 1·40 |
| Steam, . . . . . . | 0·369 | 0·480 | 1·30 |
| Hydrogen, . . . . . | 2·406 | 3·409 | 1·41 |
| Nitrogen, . . . . . . | 0·173 | 0·243 | 1·41 |
| Oxygen, . . . . . . | 0·155 | 0·217 | 1·40 |
| Carbonic oxide, . . . . | 0·173 | 0·245 | 1·41 |
| Carbonic acid, . . . . . | 0·171 | 0·216 | 1·26 |
| [illegible] . | 0·470 | 0·593 | 1·26 |

[illegible] and expansion greater. But to obtain a maximum of work, all sources of waste must be guarded against. The temperature of the gas should, at the outset, be raised to its highest limit, as much heat as possible utilised in expansion, and as little as possible wasted. It is necessary to have at our disposal a source of heat and a source of cold, the one to impart, the other to withdraw the heat. These conditions bring us to the second law of thermodynamics, known as Carnot's, because it was first laid down by him in 1824. It is as follows :—

**Carnot's Law.**—II. If heat is exchanged at constant temperature between a source of heat and a source of cold, the proportion between the quantity of heat furnished and that abstracted depends only on the absolute temperatures (Centi-

grade + 273°), and not on the nature of the body to which the heat is imparted. The expression "constant temperature" means, not that the amount of heat present does not vary, but that it varies only in proportion to the work done, so that the temperature is not affected. This law, when applied to the phenomena in a heat engine, results in what is called a "perfect cycle." It supposes the whole difference of temperature between the "heat" source and the "cold" source to be utilised in doing work, and no heat to be carried off and wasted, a condition of things, of course, impossible in practice.

But where, it will be asked, is the necessity for a source of cold? Since the more heat is added to a gas, and absorbed in expansion, the more work will be done, why should not the whole of the imparted heat be thus utilised, and none remain to be withdrawn? The reason is that, as there is an absolute zero to which no gas can ever be cooled, therefore the whole heat can never be converted into work. In a motor driven by water falling from a given height, to turn to practical account all the energy stored up in the water, it should fall to the centre of the earth! As it can only descend a given distance, from whatever height it may come, only a certain proportion of its energy can be utilised. The same law applies to the fall in temperature of a heat engine. It is only within certain limits that this range of temperature can be varied, but the wider the limits, the greater the force or energy obtained. To enlarge these limits as much as possible, heat must be added, and the temperature of the working agent raised at the beginning.

This fall in temperature of a gas, and the corresponding loss in pressure upon the piston, takes place inside the cylinder of a heat engine. To calculate the work done, it is very desirable to have a record of the actual pressures during the forward stroke. This is obtained by an instrument called an indicator, which is placed in direct communication with the cylinder, and gives a diagram marking on paper the varying pressures. The curve traced first rises abruptly, marking the sudden rise in pressure due to explosion at constant volume, and then falls gradually with increase of cylinder volume, showing how the pressures slowly decrease as the piston is driven out. To exhibit clearly the proportions between the loss of heat and pressure and the work done during the changes in the gas, two theoretical curves are used.

1. The first is known as the **Isothermal**, and signifies from its name the curve of equal temperatures. Here the piston of a cylinder moves out, by the expansion of the gas produced by the addition of heat, and the effect of the expansion is represented by a curve in which the temperature is constant, and the pressure alone falls. It has been proved that, where work is done on the piston by a gas, the temperature must fall; the isothermal curve, therefore, is based on the assumption that

heat is added to the gas, to compensate for that lost in expansion. This curve is never obtained in practice, but it is occasionally approached when the process of expansion in a heat engine is reversed, and heat is refunded to the gas by compression. In either case, the volume of the gas varies in inverse ratio to the pressure.

2. The **Adiabatic** is another theoretical curve, representing the fall in temperature when heat is neither added to nor abstracted from the working agent, but expended only in doing work by expansion on the piston. The term is derived from a Greek word signifying "impenetrable," and was first applied by Rankine. The nearer the diagrams of pressure approximate to this curve, the more perfectly will the engine utilise the heat imparted to the gas. If the difference in the specific heat of a gas at constant volume and at constant pressure be taken as representing the heat turned into work, the ratio between the two is graphically shown by the adiabatic curve. Since no heat is added or withdrawn, the temperatures of the adiabatic curve may be neglected, and the curve itself expressed only as volumes and pressures, thus $p \times v^{\gamma}$, or:—The pressures of the gas, multiplied by the volumes, raised to the power of the ratio of the two specific heats.

**Carnot's Cycle.**—Fig. 98 gives a graphic representation of Carnot's law which, plotted out in the shape of the curves just described, forms a perfect or closed cycle. Here the working agent, after passing through the phases of the addition of heat, expansion, abstraction of heat and compression, is brought back theoretically to its original condition. The processes of heating and cooling can be continuously repeated, or the sequence of operations reversed. The necessity for a source of cold is manifest. If the working agent is a gas, it must be cooled to its initial temperature, and this cannot be accomplished by the work of expansion alone. It has hitherto been found impossible in any engine to allow the gases to expand to atmosphere, and thus use in work all the heat generated. The cycle (Fig. 98) is formed of two isothermal and two adiabatic curves, and shows their theoretical forms on a small scale. The gas first receives heat from the source of heat, and expands along the line A B with increase of volume. As the temperature is not allowed to fall, the curve represents an isothermal. From B to C there is another increase of volume. The gas expands without the addition of heat, the temperature falls in consequence only of work done, and this line shows the curve of adia-

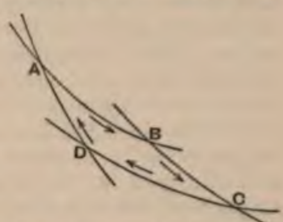

Fig. 98.—Graphic Representation of Carnot's Law.

batic expansion. At C communication is opened with the source of cold, and heat is supposed to be withdrawn along the line C D to the same extent as it was added from A to B. The volume is here diminished, and the line C D is again isothermal. From D to A the gas is compressed without heat being abstracted, and consequently increases in temperature, in proportion to the work done upon it. Compression is adiabatic, and at the end of the cycle the gas has returned to its original volume.

Actual indicator diagrams of gas engines do not usually consist of four curves. There is first the line of addition of heat, nearly vertical, then the expansion line, conforming more or less to the adiabatic, and lastly the exhaust, or discharge of the remaining heat to the cold source, which is generally nearly horizontal. (See the diagrams of the various engines.)

It is the peculiar merit of the Carnot cycle that heat is added when the gas is at its highest temperature, before any work has been done, and abstracted at its lowest, after expansion. Since the mechanical energy obtained is in strict proportion to the heat imparted to the working agent, this ideal or typical cycle furnishes and utilises the largest amount of heat. Hirn, the great French *savant*, says:—"It must be evident that this closed cycle has been designed to afford a maximum of work. The heat given up by the source of heat has been employed solely to produce work, and a maximum has therefore been obtained. The heat sent on to the refrigerator has been evolved as economically as possible, since the work has produced no variation of temperature. The object of the other two operations (along the curves C D and D A) has been solely to cause a fall and a corresponding rise in the temperatures and pressures." Thus the cycle obtained is perfect, since the heat supplied from the source of heat and by compression, is equal to the heat expended during expansion and conveyed to the refrigerator. Therefore the working agent or gas is at the close of the cycle in the same condition, that is, at the same temperature and pressure, as at the beginning. Clearly the source of heat and the refrigerator act by alternately expanding and contracting the working agent or gas.

**Carnot's Formula.**—This cycle may be expressed by the following formula, in which Q represents the quantities of heat supplied by the source of heat, and $q$ the quantities passed on to the source of cold, or in other words, rejected because they cannot be utilised. $T_1$ is the absolute highest, and $T_0$ the absolute lowest temperature, and E what is called the theoretical efficiency of the engine:—

$$E = \frac{Q - q}{Q} = \frac{T_1 - T_0}{T_1} = 1 - \frac{T_0}{T_1}$$

On this theoretical basis the heat efficiency is calculated between the highest and lowest temperatures.

*Numerical Example.*—In the Atkinson 9 H.P. engine, tested by the Committee of the Society of Arts in 1888, the temperature of the gases (Fahr.) on entering the cylinder was 576° absolute ($T_0$), and their temperature at the moment of highest explosion 2990° absolute ($T_1$). The theoretical formula of efficiency is—

$$E = \frac{T_1 - T_0}{T_1} = \frac{2990^\circ - 576^\circ}{2990^\circ} = 0\cdot 80$$

The student will here be inclined to ask what, in this simple formula, becomes of the ratios of specific heats at constant volume and pressure, the coefficient of expansion, and the other complex phenomena of expanding gases already described. They are here expressed in their simplest forms, and nothing is taken into account except the quantities of heat, and the temperatures. Now the temperatures in a heat engine must, except the initial temperature of the gases, be deduced from the pressures and volumes. It is in making these calculations that the specific heat of the gases under different conditions, the ratio of expansion to increase of temperature, and other modifying circumstances have to be considered. To calculate the work of an actual engine four or five temperatures, with their corresponding variations of volumes and pressures, must be determined and calculated from experiment. The above formula gives the method of calculation, not the process by which it has been arrived at.

**Ideal Efficiency.**—Both the highest and lowest temperatures, $T_1$ and $T_0$, in a heat engine, and the maximum amount of work which may be obtained from it, are restricted within certain limits. Even in this perfect cycle, it has been proved to be impossible for the lowest temperature, $T_0$, to fall below a given point. The highest, $T_1$, is almost as rigidly defined by the phenomena of dissociation, the power of the cast-iron cylinder and the lubricant to resist great heat, and other circumstances. A perfect engine, therefore, is not one giving unlimited expansion, and 100 per cent. of work, but one which turns all the heat supplied to it between the limits $T_1$ and $T_0$ into work. This is its maximum utilisation of heat, or what is called the "ideal efficiency" of the engine, which we will now compare with the practical efficiency, or the amount of heat a working engine can actually convert into motive power.

To obtain the highest efficiency, an ideal engine must be supposed to work with—1. A perfect gas, the volumes and pressures of which conform to the laws of Boyle and Gay-Lussac. A study of the chemical constituents of gases, and their action during combustion, shows that this conformity is never obtained in the cylinder of a gas engine. 2. No friction of the working parts. Friction generates heat, and heat we know is the equivalent of energy. Part, therefore, of the mechanical energy of the motor, which in an ideal engine cannot be taken into account,

is absorbed to produce this heat. 3. No radiation or conduction of the heat through the walls of the cylinder containing the gas. Of course it is impossible to have a vessel theoretically of this nature, that is an absolute non-conductor of heat. As soon as the gas is at a higher temperature than the surrounding atmosphere, a certain portion of the heat must be transmitted by radiation to the colder external air. 4. Lastly, expansion must be prolonged till the temperature and pressure of the gases is the same as at admission. This is also impossible. The temperature of the gases is always much higher than $T_0$, and therefore much heat is discharged at exhaust.

**Other Cycles.**—In the diagram shown at Fig. 98 the curves A B C D enclose an area representing not only the heat supplied, but the amount of work done by a heat engine. The curves, and therefore the shape of the area, may, however, vary according to the way in which the heat is supplied to, and withdrawn from the engine, or according to the expansion and compression of the charge. Figs. 99 and 100 represent two other

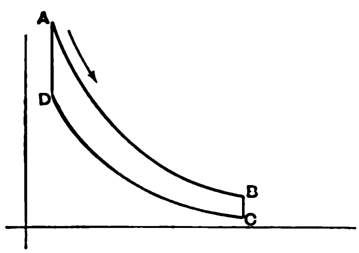


Fig. 99.—Constant Volume.

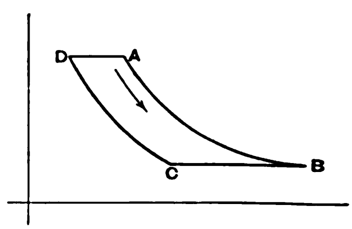


Fig. 100.—Constant Pressure.

theoretical cycles known, the first as Stirling's, the second as Ericsson's. Though the curves are here of different lengths they are, like those forming Carnot's cycle, theoretically perfect, and form the boundaries of an equal area. Heat is added in both cycles from D to A, and abstracted from B to C, and these lines are designated by Professor Witz "isodiabatic," or lines of equal transmission of heat. The curves A B and C D are no longer adiabatic, but isothermal. The first represents the whole of the useful conversion of heat into work at constant temperature; in the second the heat is refunded, and the same amount restored to the gas by compression as was expended in work. The lines B C and D A are straight, parallel in the one case to the vertical line, called an ordinate, at the left hand of Fig. 99, and in the other to the horizontal line (abscissa) at the bottom of ʼig. 100. The areas enclosed within these curves form the bases calculation of all diagrams representing work done in any at engine. The ordinates in a diagram are in proportion to

the pressures in the cylinder, the abscissæ to the length of stroke.

The horizontal lines in these figures represent the volumes of the cylinder. Along this line the piston may be said to travel, driven forward by the expanding force of the gas, and the farther it moves to the right the larger the cubic contents of the cylinder. If the piston is moved half way along the horizontal line, half the volume of the cylinder, reckoning from the dead point, will be uncovered by it. The horizontal line in an indicator diagram, therefore, represents volumes of the cylinder or lengths of stroke, and distances along it are calculated in feet or metres. The vertical line in the figures, and in indicator diagrams of heat engines, represents the pressures of the gas obtained by the addition of heat, and is usually divided into sections reckoned as so many lbs. pressure per square inch of piston surface. So that we get horizontally *feet*, and vertically *lbs.*, or ft. × lbs. = power proportioned to area of diagram.

**Indicator Diagrams.**—It will make the study of the heat engine easier to the student if we describe here how an actual indicator diagram is taken, and the kind of instrument used to trace it. The same type of apparatus is employed in gas as in steam engines. It consists of a small piston and cylinder in direct communication with the inside of the motor cylinder; the piston is forced up or down with the varying internal pressures produced by the expansion of the gas. To the upper part of this piston is attached a small pencil. A drum covered with paper is made to travel to and fro at the same relative speed as the motor piston. The apparatus is so arranged that as the drum moves horizontally, the pencil of the indicator piston moves vertically. The pencil goes up and down in proportion to the cylinder pressures (lbs.) and the paper travels to and fro in proportion to the strokes (ft.) These two movements are brought in contact, and the pencil traces a diagram on the paper (see Fig. 102, p. 237). The vertical lines of this diagram represent lbs. pressure per square inch on the piston surface, and the horizontal lines feet travelled through by the piston.

The pressures and the volumes of a gas being known from the indicator diagram, the temperatures are usually calculated from them. To determine these temperatures in a gas engine is, however, a difficult process, because many scientific men are of opinion that, at the moment of explosion, the gases in the cylinder are not at a uniform temperature throughout. In the two closed cycles given in Figs. 99 and 100 the lines of addition and abstraction of heat, D A and B C, are in the first figure parallel to the pressures, in the other to the volumes. This means that in Fig. 99 the heat is supposed to be added from the source of heat and withdrawn, while the volume remains constant, and the piston stationary at either end of the cylinder.

[illegible] while the pressure [illegible] and the [illegible] heat must be added [illegible] because [illegible] The two [illegible] of specific heat at [illegible]

[illegible] diagram of pressures [illegible] much heat [illegible] determine

[illegible]

[illegible] work done, or at [illegible] these conditions, [illegible] deficiencies [illegible] been mentioned. [illegible] between the [illegible] actual results [illegible] this difference. [illegible] necessary. Not [illegible] amount of heat supplied [illegible] and when the [illegible] eliminate the [illegible] necessary.

**Measurements of Heat.**—[illegible] it is [illegible] measurement of heat [illegible] total amount of heat [illegible] to represent [illegible] in the cylinder, [illegible] what he calls a diagram of heat. [illegible] Professor Zeuner, [illegible] measurement of heat. In a diagram of this kind the volumes do not appear. The horizontal lines indicate the pressures, the vertical lines the temperatures in the cylinder of a heat engine. The area formed by them shows the work obtained, resulting from the temperatures and pressures in the cylinder, at different points of the stroke. The pressures being determined from the indicator diagram, the temperatures can be calculated from them, and the variations during the stroke obtained. The results arrived at, though somewhat complex, are more reliable than those given by other methods.

## CHAPTER XVII.

## THE CHEMICAL COMPOSITION OF GAS IN GAS ENGINES.



IN the preceding chapter we have seen that a gas engine is simply one form of heat engine, and that its object is to transform heat into work through the medium of gas—the working agent. We now want to know, further, how this process is carried on with maximum efficiency, so that the largest possible proportion of the whole heat we add to the agent may be converted into useful work.

We must, therefore, examine more closely into the nature, composition, and specific properties of the gas employed.

The object of this chapter is to determine—

1. What coal gas is;
2. How much air is required to burn it;
3. How much heat is given out during combustion, and carried away by the residual gases.

As the nomenclature adopted by chemists renders the treatment of the problem of combustion of gases very simple, it will be convenient to begin with a brief explanation of its main principles.

**Atoms and Molecules.**—All apparently homogeneous substances are composed of extremely small particles, called *molecules*, which, for any given substance, have the same weight.

These molecules, which are the smallest particles of the substance which can exist in the free state, are, in general, composed of still smaller particles, called *atoms*. If all the atoms in the molecules are identical, the substance is known as an *element*, inasmuch as in this case, it is not possible to break it up into two or more distinct bodies. If, on the other hand, two or more different kinds of atoms exist in the molecule, it is known as a *compound*.

The fundamental law upon which chemistry at the present day is based, first enunciated by Avogadro, is—"Equal volumes of gases (under the same conditions of temperature and pressure) contain equal numbers of molecules."

There is another way of stating this, which is sometimes useful. Take a cubic foot of any gas, say oxygen, at a fixed temperature and under a fixed pressure. It contains $n$ molecules, where $n$ is a very large number, only roughly known, and the exact value of which is not required here. The *average space* occupied by a molecule of oxygen then, is $\frac{1}{n}$ cubic feet. This is called the "molecular volume" of oxygen. Now, since the same volume of any other gas, say hydrogen, by the law first enunciated, also contains $n$ molecules, its molecular volume is also $\frac{1}{n}$ cubic feet. Hence, another way of stating Avogadro's law is—"All gases have the same molecular volume."

To resume then—

1. All atoms of the same element have the same weight.
2. All molecules of the same compound have the same weight and the same volume.

**Chemical Symbols.**—As an abbreviation for one atom of an element, the first letter or first two letters of the word is used; thus, C stands for an atom of carbon, H for an atom of hydrogen, O for an atom of oxygen, N for nitrogen, S for sulphur, and so on. Two letters placed together represent a molecule of a compound; thus, CO denotes one molecule of the compound carbonic oxide, formed by the combination of one atom of carbon C, and one atom of oxygen O. Similarly $CO_2$ denotes a molecule of the compound carbonic acid, containing three atoms, one of carbon and two of oxygen. $2CO_2$ denotes *two* molecules of carbonic acid.

**Atomic Weights.**—Now the actual weights of the atoms are excessively minute, and are only known very roughly indeed. But the *relative* magnitude of the weights of the atoms of the various elements can be, and has been determined with very considerable accuracy. It is customary to take the weight of the lightest known atom, hydrogen, as unity; and the values for "atomic weight" found in works on chemistry, represent the weights of the atoms of the various elements as multiples of this.

All the gaseous elements dealt with here contain two atoms in each molecule. Thus $H_2$, $N_2$, $O_2$ are the molecular formulæ for the elementary gases—hydrogen, nitrogen, oxygen respectively. From this, and with Avogadro's law, it is easy to find the atomic weights of nitrogen and oxygen. It is found that 1 cubic foot of hydrogen weighs ·005591 lb. under standard conditions of pressure and temperature, 1 cubic foot of oxygen weighs ·089456 lb., and of nitrogen, under the same conditions, ·07828 lb. These numbers are in the ratio of 1 : 16 : 14. Hence, if $nH_2$ = 1 unit of weight, by Avogadro's law the same

number $nO_2 = 16$ units of weight, and $nN_2 = 14$ units of weight—*i.e.*, the atomic weights of hydrogen, oxygen, and nitrogen are as 1 : 16 : 14. The only atomic weights required in this chapter for gas engines are :—

TABLE OF ATOMIC WEIGHTS.

| Element. | Hydrogen. | Oxygen. | Nitrogen. | Carbon. | Sulphur. |
|---|---|---|---|---|---|
| Symbol, . . | H | O | N | C | S |
| Weight of atom (in round numbers) | 1 | 16 | 14 | 12 | 32 |

*Molecular Weights.*—The "molecular weight"—*i.e.*, the total weight of each molecule, when the hydrogen *atom* is the unit of weight, is obtained by simply adding together the weights of its constituent atoms. Thus the molecular weight of hydrogen, $H_2$, is 2; of oxygen, $O_2$, is 32; of carbonic oxide, CO, $12 + 16 = 28$; of marsh gas, $CH_4$, $12 + (1 \times 4) = 16$. Hence the weight of 1 cubic foot of hydrogen being ·00559 lb., that of a cubic foot of carbonic oxide is $\left(\frac{16 + 12}{2}\right) = 14 \times \cdot 00559$; of marsh gas, $\frac{4 + 12}{2} = 8 \times \cdot 00559$; and so on for any other gas.

**Specific Heat.**—If a quantity of heat is added to a gas it may result in an increase of pressure, temperature, or volume, or in an increase of all three. Thus, there may be several "specific heats." The only two generally used are :—

(1) The specific heat at constant volume, which is defined as the number of units of heat required to raise the temperature of the unit weight of gas through 1°, the volume of the gas remaining constant; and

(2) The specific heat at constant pressure, where the gas is allowed to do work by expanding.

Of these the former, which is obviously the smaller number, is sometimes termed the "true specific heat," all the heat going in this case to increase the internal energy of the gas.

For the elementary gases, hydrogen, oxygen, and nitrogen, and also for carbonic oxide, it is found that the amount of heat required to raise equal volumes through 1° is very nearly the same; or, in other words, that the specific heat × molecular weight = constant. It is also found that the specific heats are nearly independent of the temperature, tending only to increase very slightly with it. For the more complicated molecules, such as marsh gas, $CH_4$, ethylene, $C_2H_4$, &c., which occur in

coal gas, neither of these relations hold, the amount of heat required to raise, say 1 cubic foot of ethylene through 1° F., is sensibly different from that required to raise the same volume of air through 1°F., and, further, the specific heat increases very rapidly with the temperature.

The table of specific heats will be found on p. 213.

**Chemical Equations.**—Chemical equations are symbolic representations of chemical changes. It will be convenient to take one equation as a type and explain it in detail. The following is a useful example:—

$$\underset{\text{Methane.}}{\underset{(12 + 4)}{CH_4}} + \underset{\text{Oxygen.}}{\underset{2\,(32)}{2O_2}} = \underset{\text{Carbonic Acid.}}{\underset{(12 + 32)}{CO_2}} + \underset{\text{Steam.}}{\underset{2\,(2 + 16)}{2H_2O}}$$

This is interpreted as follows:—Since 1 *molecule* of methane combines with 2 *molecules* of oxygen, it follows, by Avogadro's law, that 1 *volume* of methane combines with 2 *volumes* of oxygen, giving 1 *volume* of carbonic acid and 2 *volumes* of steam. This same equation also expresses the fact that 16 lbs. of methane require 64 lbs. of oxygen for complete combustion, and give as the resulting products 44 lbs. of carbonic acid and 36 lbs. of steam. By the term "complete combustion" is meant that the hydrocarbon combines with the maximum possible amount of oxygen, giving carbonic acid and water only as the final products.

When the quantity of oxygen required for the combustion of each constituent is known, the next step is to determine the heat evolved by combustion. As this heat cannot be measured in the cylinder of an engine, the calorimetric value of the gas is obtained by burning it in oxygen. For this purpose an instrument is employed, called a calorimeter. MM. Favre and Silbermann were the first to design an apparatus for testing the heating values of solid, liquid, and gaseous fuels, and other calorimeters have since been brought out.

**Heat of Combustion of Gas.**—The amounts of heat developed by the complete combustion of the various carbon compounds contained in coal gas, have been experimentally determined in two ways. Firstly, by burning a current of the gas in question in oxygen or air at the ordinary atmospheric pressure, and, secondly, by exploding a mixture of the two gases in a strong steel "bomb."

The advantages of the second method, which was first used by Andrews, and has been recently employed in an improved form by M. Berthelot and M. Mahler, are that the combustion takes place at constant volume, and that on account of the much shorter time occupied by the reaction, the "corrections for cooling" of the calorimeter are very much reduced.

One gramme of the fuel, the heating value of which is to be determined, is introduced into the closed vessel or bomb, placed within an outer shell filled with water. Pure oxygen is then admitted to the inner vessel at a pressure of 25 atmospheres, the mixture is instantaneously fired by the electric spark, and the rise in temperature of the surrounding water shows the heat evolved during combustion. Extremely delicate thermometers are used, marking the rise in temperature to within $\frac{1}{100}$ of a degree. M. Berthelot lined his inner vessel or calorimetric bomb with platinum, to resist the sudden and intense heat. This metal is very costly, and a less expensive calorimeter has lately been introduced by M. Mahler, in which the "bomb" is of steel lined with enamel, but it is similar to Berthelot's design in other respects.

With the help of this apparatus, the heat of combustion of coal and other fuels, solid and liquid, and of most kinds of combustibles, has been determined. The following table gives the values by the different authorities of the heat produced by the combustion of the chemical constituents of coal gas, and also of solid carbon :—

Heat produced by the Combustion of H, C, CO, &c. (from Ostwald's *Verwandtschafts-Lehre*, 1887).

| Unit Weight or Gramme of | Units of Heat evolved by Complete Combustion of 1 gramme at 17° C., and Atm. Pressure. | | | |
|---|---|---|---|---|
| | Favre and Silbermann. | Thomsen. | Berthelot. | Thomsen. |
| | Cal. | Cal. | Cal. | B.T.U. |
| Hydrogen, H, . . . | 34,460 | 34,180 | 34,600 | 61,560 |
| Carbon, C, . . . | 8,080 | 8,080 | 8,138 | 14,540 |
| Carbonic oxide, CO, . | 2,403 | 2,429 | 2,439 | 4,372 |
| Marsh Gas, $CH_4$ . . | 13,062 | 13,244 | 13,344 | 23,850 |
| Ethylene, $C_2H_4$, . . | 11,857 | 11,907 | 12,193 | 21,430 |
| Benzene, $C_6H_6$, . . | 9,915 | 10,249 | 9,949 | 18,448 |

That is to say, 1 gramme of carbon completely burnt gives out sufficient heat to raise the temperature of 8,080 grammes of water 1° C. or 1 gramme water 8,080° C. according to Favre and Silbermann's reckoning. MM. Berthelot and Mahler claim to have obtained more accurate results with their new calorimeters, owing to the more rapid and complete method of combustion; their values are slightly higher.

The following table shows the number of British thermal units given out by the complete combustion of 1 cubic foot of each of the gases usually present in coal gas:—

TABLE OF B.T.U. RESULTING FROM THE COMPLETE COMBUSTION OF 1 CUBIC FOOT OF DIFFERENT GASES.

| Name of Gas. | Calorific Values, at Ordinary Temperature and Pressure, per Cubic Foot (measured at 32° F. and 30 ins. pressure of Mercury) in B.T.U. (British Thermal Units.) |
|---|---|
| Hydrogen, . . . . . . | 293·5 |
| Carbonic oxide, . . . . . | 342·3 |
| Methane, . . . . . . | 1,066 |
| Ethylene, . . . . . . | 1,678 |
| Propylene, . . . . . . | 2,479 |
| Butylene, . . . . . . | 3,275 |
| Benzene, . . . . . . | 4,023 |

The unit of heat used here is the amount of heat required to raise 1 lb. of water, at 64° to 65° F., 1° F. The difference between the specific heats of water at 0° C. and water at 19° is only about 1 in 1,000. The products are supposed to be cooled down to about 19° C. As the figure given for hydrogen includes the latent heat of steam, it may be replaced by the figure 52,500,* in which this latent heat remains in the steam gas.

**Composition of Coal Gas.**—As regards the actual composition of coal gas, the following table, taken from Schöttler, shows an average composition of 1 cubic foot of ordinary Hanover lighting gas, distilled from coal in retorts, without admixture of air:—

TABLE SHOWING AVERAGE COMPOSITION OF 1 CUBIC FOOT OF HANOVER COAL GAS (*Schöttler*).

| Volume. | Name of Gas. | Chemical Symbol. |
|---|---|---|
| Cubic Feet. | | |
| ·0069 | Benzene. | $C_6H_6$ |
| ·0057 | Butylene. | $C_4H_8$ |
| ·0211 | Ethylene. | $C_2H_4$ |
| ·3735 | Methane. | $CH_4$ |
| ·4627 | Hydrogen. | $H_2$ |
| ·1119 | Carbonic oxide. | $CO$ |
| ·0081 | Carbonic acid. | $CO_2$ |
| ·0101 | Nitrogen. | $N_2$ |
| 1·0000 | | |

The first three gases are called "heavy hydrocarbons," and as they are all frequently absorbed together by the same reagent (fuming sulphuric acid), they are generally included together under one head.

* 52,500 B.T.U. in 1 lb. H., ∴ 52,500 × 0·00559 (weight 1 cubic foot H. per lb.) = 293·5.

***Benzene***, $C_6H_6$, burns with excess of oxygen as follows:—

Molecular weight, 78; weight of 1 cubic foot = 39 × ·005591 = ·2181 lb.

$$\begin{array}{ccccccc} {}^*C_6H_6 & + & 7\tfrac{1}{2}O_2 & = & 6CO_2 & + & 3H_2O \\ (1 \text{ vol.}) & + & (7\tfrac{1}{2} \text{ vols.}) & = & (6 \text{ vols.}) & + & (3 \text{ vols.}) \end{array}$$

*Butylene*, $C_4H_8$ (Synonym—Tetrylene).

$$\begin{array}{ccccccc} C_4H_8 & + & CO_2 & = & 4CO_2 & + & 4H_2O \\ (1 \text{ vol.}) & + & (6 \text{ vols.}) & = & (4 \text{ vols.}) & + & (4 \text{ vols.}) \end{array}$$

Molecular weight, 56; weight of a cubic foot, 28 × ·005591 = ·1566 lb.

*Ethylene*, $C_2H_4$ (Synonyms—Olefiant gas, ethene).

$$\begin{array}{ccccccc} C_2H_4 & + & 3O_2 & = & 2CO_2 & + & 2H_2O \\ (1 \text{ vol.}) & + & (3 \text{ vols.}) & = & (2 \text{ vols.}) & + & (2 \text{ vols.}) \end{array}$$

Molecular weight, 28; weight of a cubic foot, 14 × ·005591 = ·0783 lb.

*Methane*, $CH_4$ (Synonyms—Marsh gas, firedamp).

$$\begin{array}{ccccccc} CH_4 & + & 2O_2 & = & CO_2 & + & 2H_2O \\ (1 \text{ vol.}) & + & (2 \text{ vols.}) & = & (1 \text{ vol.}) & + & (2 \text{ vols.}) \end{array}$$

Molecular weight, 16; weight of a cubic foot, 8 × ·005591 = ·04472 lb.

*Hydrogen*, $H_2$.

$$\begin{array}{ccccc} {}^*H_2 & + & \tfrac{1}{2}O_2 & = & H_2O \\ (1 \text{ vol.}) & + & (\tfrac{1}{2} \text{ vol.}) & = & (1 \text{ vol.}) \end{array}$$

Molecular weight, 2; weight of a cubic foot, ·005591 lb.

*Carbonic Oxide*, CO (Synonym—Carbon monoxide).

$$\begin{array}{ccccc} {}^*CO & + & \tfrac{1}{2}O_2 & = & CO_2 \\ (1 \text{ vol.}) & + & (\tfrac{1}{2} \text{ vol.}) & = & (1 \text{ vol.}) \end{array}$$

Molecular weight, 28; weight of a cubic foot, 14 × ·005591 = ·0783 lb.

*Carbonic Acid*, $CO_2$ (Synonyms—Carbonic anhydride, carbon dioxide).

Molecular weight, 44; weight of a cubic foot, 22 × ·005591 = ·123 lb.

*Nitrogen*, $N_2$, does not play any active part in the combustion, but remains unchanged throughout the whole set of operations. It acts as a mere diluent.

Molecular weight, 28; weight of a cubic foot, 14 × ·005591 = ·0783 lb.

Since the whole of the oxygen represented in the above equations has to come from the air, and since there are in the air 79 volumes of nitrogen to 21 of oxygen, it follows that one volume of oxygen must be replaced by about 4·762 of air.

... e, these equations should be doubled, but the ... clearly shown as they are. Of course, half a ... ssibility.

The preceding data may be conveniently tabulated as follows:—

TABLE SHOWING PRODUCTS OF COMBUSTION OF THE VARIOUS CONSTITUENTS OF COAL GAS.

| Name. | Formula. | Density in lbs. per cub ft. at 0° C. and 760 mm. pressure. | Volumes Oxygen required for Complete Combustion. | Volumes of Air. | Volumes $CO_2$ Produced. |
|---|---|---|---|---|---|
| Benzene, . . . | $C_6H_6$ | ·2181 | 7½ | 35·71 | 6 |
| Butylene, . . . | $C_4H_8$ | ·1566 | 6 | 28·57 | 4 |
| Ethylene, . . . | $C_2H_4$ | ·0783 | 3 | 14·28 | 2 |
| Methane, . . . | $CH_4$ | ·0447 | 2 | 9·52 | 1 |
| Hydrogen,. . . | $H_2$ | ·00559 | ½ | 2·38 | 0 |
| Carbonic oxide, . | CO | ·0783 | ½ | 2·38 | 1 |
| Carbonic acid, . | $CO_2$ | ·1230 | ... | ... | ... |
| Nitrogen, . . . | $N_2$ | ·0783 | ... | ... | ... |

The composition of lighting gas is not constant. It depends upon the quality of the coal, the temperature of the retort, and the period of distillation. The following table, from experiments by Dr. Wright,* shows the influence of the time that has elapsed after charging the retorts.

COAL GAS.

| Constituents. | | Time after Commencement of Distillation. | | |
|---|---|---|---|---|
| | | 10 minutes. | 3 hours 25 min. | 5 hours 35 min. |
| Hydrogen, . . | $H_2$ | ·2010 per ct. | ·5268 per ct. | ·6712 per ct. |
| Marsh gas. . . | $CH_4$ | ·5738 ,, | ·3354 ,, | ·2258 ,, |
| Carbonic oxide, . | CO | ·0619 ,, | ·0621 ,, | ·0612 ,, |
| Heavy hydrocarbons, . . . | ... | ·1062 ,, | ·0304 ,, | ·0179 ,, |
| Nitrogen, . . . | $N_2$ | ·0220 ,, | ·0255 ,, | ·0078 ,, |
| Carbonic acid, . | $CO_2$ | ·0221 ,, | ·0149 ,, | ·0150 ,, |
| Sulphuretted hydrogen, . . . | $SH_2$ | ·0130 ,, | ·0049 ,, | ·0011 ,, |
| Cub. ft. | | 1·0000 ,, | 1·0000 ,, | 1·0000 ,, |

The following table shows the composition of the coal gas in most of the large towns of Europe, &c. :—

* *Journ. Chem. Soc.*, No. 261, 1884.

## COMPOSITION OF COAL GAS IN VARIOUS CITIES AND TOWNS, IN PERCENTAGE BY VOLUME.

| Constituents in Gas. Percentage by Volume. | London Gas-Light and Coke Co. | London Society of Arts' Trial. | Manchester. | Kilmarnock Trial, Prof. Kennedy. | Gas-Motoren Fabrik Cologne (Slaby). | Bonn (Clerk). | Dresden (Schöttler) | Hanover (Schöttler). | Hoboken New-York (Brooks & Steward). | Paris (Peclet). | Paris (Witz). |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Heavy hydro-carbons, . . | 4·41 | 3·77 | 6·46 | 5·55 | 3·50 | 4·75 | 3·00 | 3·17 | 6·60 | 5·80 | 5·50 |
| Marsh gas, $CH_4$, | 37·64 | 37·34 | 34·90 | 42·80 | 34·40 | 43·12 | 33·40 | 37·55 | 37·30 | 33·10 | 32·30 |
| Hydrogen, H, . | 47·99 | 50·44 | 45·58 | 43·60 | 56·90 | 39·80 | 48·70 | 46·27 | 39·50 | 50·10 | 52·80 |
| Carbonic oxide, CO, . . . . | 3·75 | 3·96 | 6·64 | 4·30 | 5·20 | 4·66 | 8·00 | 11·19 | 4·30 | 6·30 | 5·60 |
| Carbonic acid, $CO_2$, . . . | ... | 0·51 | 3·67 | | | 3·02 | 1·50 | 0·81 | 2·70 and impurities. | 1·50 | ... |
| Oxygen, O, . . | 0·26 | ... | ... $H_2S$ 0·29 | 1·05 | ... | ... | 1·40 | ... | 1·40 | 0·50 | ... |
| Nitrogen, N, . | 5·95 | 3·98 | 2·46 | 2·70 | ... | 4·65 | 4·00 | 1·01 | 8·20 | 2·70 | 3·80 |
| Totals, . . | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 |

**Calorific Value of 1 Cubic Foot of any Coal Gas.**—From the table of B.T.U., p. 226, it is now easy to find the calorific value of 1 cubic foot of any lighting gas, it being only necessary to multiply the volume percentage of each combustible gas by its calorific power per cubic foot, as given in the second column of that table.

Take for example the following gas :—

| Name of Gas. | Volumes in cub. ft. | Calorific Value B.T.U in 1 cub. ft. | Weight in lbs. per cub. ft. | Volumes Oxygen required. |
|---|---|---|---|---|
| Methane, | ·4280 | 456·2 | ·019130 | ·8560 |
| Ethylene, | ·0277 | 46·5 | ·002169 | ·0831 |
| Butylene, | ·0278 | 91·0 | ·004353 | ·1668 |
| Hydrogen, | ·4360 | 128·0 | ·002437 | ·2180 |
| Carbonic oxide, | ·0430 | 14·7 | ·003366 | ·0215 |
| Nitrogen, $CO_2$ and $O_2$, | ·0375 | ... | ·003220 | ... |
| | 1·0000 | 736·4 | ·034680 | 1·3454 |

*i.e.*, 1 cubic foot of this gas on complete combustion would yield 736·4 B.T.U., or $\frac{736{\cdot}4}{{\cdot}03468} = 21{,}230$ B.T.U. per lb. of gas, and would require 1·345 volumes of oxygen or 6·407 of air for complete combustion.

As a matter of fact, when 1 cubic foot of this gas is mixed with 1·345 volumes of oxygen, the explosion is so violent as to be quite unmanageable. Even when diluted with nitrogen as in air, the correct proportions for complete combustion (here 6·407 volumes of air to 1 of coal gas) still give too violent an explosion. This can be moderated by using an excess of air which acts as a diluent, lowering the partial pressure of the re-acting gases. This excess of air, together with the whole of the 5·062 volumes of nitrogen introduced with the re-acting oxygen, and the nitrogen originally present in the gas, unavoidably impairs the efficiency, as the whole of this has to be heated up to the temperature of the cylinder gases. Further, it is discharged at a high temperature (about 400° to 450° C.) together with the carbonic acid produced in the reaction, and the whole of this heat is wasted. In the various producer and water gases, formed by forcing air or mixtures of air and steam over red-hot coal, the amount of nitrogen is considerable, and accordingly much less air is required for their complete combustion. Thus, wherever coal gas requires from 6 to 15 volumes of air, Dowson gas requires only 1½ volumes.

The following table gives the composition of several of these cheaper gases :—

TABLE OF COMPOSITION OF POOR GASES.

| Name of Gas. | Oxygen, O, vol. per cent. | Hydrogen, H, vol. per cent. | Marsh Gas, $CH_4$, vol. per cent. | Olefiant Gas, vol. per cent. | Carbonic Oxide, CO, vol per cent. | Carbonic Acid, $CO_2$, vol. per cent. | Nitrogen, N, vol. per cent. |
|---|---|---|---|---|---|---|---|
| Producer gas (Siemens'), | ... | 8·6 | 2·4 | ... | 24·4 | 5·2 | 59·4 |
| Water gas, . . . | 0·10 | 50·50 | 0·60 | ... | 44·40 | 1·60 | ... |
| Strong gas, . . . | ... | 53·0 | ... | ... | 35·0 | 4·0 | 8·0 |
| Lowe gas, . . . | ... | 30·0 | ... | ... | 28·0 | 34·0 | 8·0 |
| Dowson gas, . . . | 0·03 | 18·73 | 0·31 | 0·31 | 25·07 | 6·57 | 48·98 |
| " . . . | 0·23 | 24·36 | 1·16 | 0·15 | 17·55 | 6·07 | 50·48 |
| Lencauchez, . . . | 0·50 | 20·00 | ... | 4·0 | 21·00 | 5·00 | 49·50 |

It may be useful, as an example, to work out the calorific value of one of these, say Siemens' producer gas :—

HEATING VALUE OF 1 CUBIC FOOT OF SIEMENS' PRODUCER GAS IN BRITISH THERMAL UNITS.

| Gas. | Symbol. | Amount in 1 cub. ft. | Calorific Value per cub. ft. | Calorific Value per cub. ft. of Gas in B.T.U. | Volumes of Oxygen required in cub. ft. | Volumes of Air required in cub. ft. |
|---|---|---|---|---|---|---|
| Hydrogen, . . . | $H_2$ | ·086 | 293·5 | 25·24 | ·043 | ·205 |
| Methane, . . . | $CH_4$ | ·024 | 1066·0 | 26·58 | ·048 | ·229 |
| Carbonic oxide, . | CO | ·244 | 342·0 | 83·51 | ·122 | ·581 |
| Carbonic acid, . | $CO_2$ | ·052 | ... | ... | ... | ... |
| Nitrogen, . . . | $N_2$ | ·594 | ... | ... | ... | ... |
| | | 1·000 | ... | 135·33 | 0·213 | 1·015 |

Hence the calorific power of this producer gas is, roughly speaking, only one-fifth that of an equal volume of coal gas, and it requires only a little more than its own volume of air for complete combustion.

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## CHAPTER XVIII.

## THE UTILISATION OF HEAT IN A GAS ENGINE.

CONTENTS.—Gas Power *versus* Steam—Balance of Heat—Four Eff[illegible] —Ideal Diagram—Actual Otto Diagram—Formulæ of [illegible] Four Types of Engine—Heat Balance Sheet.

HAVING now considered the laws governing [illegible] nature of the changes taking place in the [illegible] in an engine cylinder, and the heat develop[illegible]

question how far this heat is really usefully employed as motive power. Upon this vital point the whole theory and practice of a heat engine rest. The heat supplied is used to drive out a piston, but it can never all be turned into work. The analyses and calculations of the heat of gases in the preceding chapter enable us to determine how much heat goes into a motor cylinder, and we must now try and trace what becomes of it. What is the proportion wasted and utilised? What are the causes of the waste of heat, and consequently of power, and how far can this loss be avoided, in the construction and working of a heat engine?

An erroneous idea is sometimes prevalent that heat is a mysterious attribute imparted to a body, which cannot be measured or accounted for. The heat evolved in a gas by combustion in a cylinder does not disappear in some unknown manner. Either it remains to raise the temperature of the gas, or it is dissipated in one of three different ways. A certain quantity is radiated into the atmosphere through the walls of the cylinder, and into the water jacket. Some is expended in power, according to the law of the mechanical equivalent; and a proportion, varying according to the more or less perfect cycle of the engine, is left at the close of expansion, to be carried off into the atmosphere at the exhaust stroke.

**Gas Power as Compared with Steam.** — Both in theory and in practice the gas engine even now, although it is only of late years that it has been carefully studied, turns more heat into work than a steam engine. This is chiefly because the range of working temperatures is very much higher. In a boiler and steam engine the source of heat, the furnace, is separated from the engine, and the steam is raised to its highest temperature before it enters the cylinder. However carefully the steam pipes may be covered, they carry off some heat. The temperature of the working agent cannot be so great when heat is added externally, before work on the piston is begun, as when it is imparted actually inside the cylinder, as in a gas motor. When the water in a boiler is converted into steam, a change of physical condition takes place. A certain quantity of heat becomes latent, or is stored up without raising the temperature of the steam, in order to produce the change from a liquid to a gaseous state. Nor does steam wholly conform to the law of Gay-Lussac, because it is not a perfect gas. It increases more rapidly in pressure than in temperature, when heat is applied to it. At a temperature of 450° C absolute, it has a pressure of 10 atmospheres = 150 lbs. to the square inch. From these causes the initial temperature of the steam is relatively low; the range, or difference between the two sources, is never very great, and consequently less heat is available to be utilised in work. The efficiency of a well-jacketed modern steam engine may be taken

at from 8 to 14 per cent., depending on the speed, pressure, &c. —that is, about one-seventh or one-twelfth of the heat received by the engine is turned into work (exclusive of boiler).

In gas engines the conditions are very different. Combustion generally takes place in the cylinder itself, or in a contiguous chamber, and there is no boiler or its equivalent. The gas is introduced into the cylinder at a comparatively low temperature. The heat is produced at once by explosion and combustion, and utilised on the piston. The theoretical temperature of explosion obtained by calculating the heat of combustion of the chemical constituents of the gas, is estimated at from 2,600° to nearly 4,000° C. As there is no change of physical state in the gas, no absorption of latent heat takes place. To these two causes, viz., internal combustion, and permanence of physical state in the gas, the greater practical efficiency of a gas engine is chiefly due. As compared with steam, it turns into work about twice as much, or from 15 to 22 per cent. of the total heat supplied to it, according to speed, size of engine, &c. From these figures, however, it must not always be assumed that, in all cases, the power at the end of the crank shaft is obtained more economically, because the mechanical efficiency of the gas engine, or the ratio of brake to indicated horse-power, is generally lower than that of a steam engine. In other words, a gas engine often takes more power to drive itself than a steam engine.

But there are limits to the heat obtained by internal combustion in a gas engine cylinder. Far more heat is developed than can be utilised, or brought safely into contact with the working parts of the engine. Professor Witz says that the limit of working temperature in a heat engine throughout the stroke, is estimated at about 573° absolute = 300° C. It is true that much higher temperatures are obtained in a gas engine; they cannot indeed be avoided, but neither can they at present be properly utilised. A temperature of 1,600° C. or 1,873 absolute is taken by the best authorities (for it is impossible to determine it directly) as an average maximum temperature of explosion, and it is seldom lower than 1,000 C. or 1,273° absolute. Such heat must be instantly counteracted and dispersed, and this is obtained by circulating water in the jacket round the cylinder, and thus lowering the temperature of the gas at explosion and afterwards. If it were not for these practical difficulties, the 20 per cent. actual efficiency mentioned above would be considerably increased. In the formula $\frac{T_1 - T_0}{T_1}$, p. 216, $T_1$ is the maximum temperature of explosion. Practically about one-third to one-half this heat $T_1$ is carried off by the action of the walls and water jacket, and much of the remainder escapes with the unburnt gases. The colder walls abstract heat which

must be dispersed, but might with great advantage be retained. Their action is necessary, but not perhaps to its full extent, and here is a great opening for future improvement.

**Balance of Heat.**—A most useful method of studying heat and its utilisation in any engine was first introduced by the late G. A. Hirn. He drew up what he termed a heat balance sheet, showing on one side all the heat given to an engine, and on the other how it was expended. It is now usual, following his method, to make such a heat balance, in calculating the results of an engine. The heat received is put on one side of the account, and that dissipated, measured, and unaccounted for on the other. In a gas engine such a heat account, as shown by actual experiments, is about as follows :—

GAS ENGINE—HEAT BALANCE ACCOUNT.

| *Dr.* Heat received by the Engine. | | Heat accounted for, &c. *Cr.* | |
|---|---|---|---|
| | Per Cent. | | Per Cent. |
| Heat units (T.U.) received per explosion, | 100 | In work (T.U.). . . | 22·32 |
| | | Carried off by jacket, . | 32·96 |
| | | Carried off in exhaust gases, . . . . | 43·29 |
| | | Carried off by conduction and radiation and unaccounted for, . . | 1·43 |
| Total, | 100 | Total, | 100 |

Of course, the figures vary much with different engines, but the above may be taken to represent good working conditions. They are drawn from Professor Capper's trial of a 7 nominal H.P. Crossley engine, Appendix, p. 355. (See other Heat Balance Accounts on p. 242.)

The actual heat supplied to an engine cannot be calculated, unless the calorific value of the gas is known, and the most accurate method of determination is by chemical analysis. The gas varies sometimes from hour to hour in the proportions of its chemical constituents, and its heating value differs in every town. The amount of air used to dilute the charge is also an element of uncertainty in making calculations. The ordinary method is to measure the quantity of gas entering the cylinder by a meter, and to calculate the air consumption from the total volume, but this is an unsatisfactory plan. A certain amount of the products of combustion almost always remain in the cylinder, mixing with the fresh charge, and as the quantity of gas admitted does not vary, they must reduce the proportion of air entering with it. The quantity of air should

be actually measured, and this has been done by Dr. Slaby and others.

**Expansion.**—The utilisation of heat in a gas engine, and its transformation into work, is mainly obtained during the two processes of expansion and compression. The uses of compression, and the great advantages derived from it, have already been explained. It reduces the original volume of the gases, and increases their power of expansion. But since the temperature obtained by explosion in a gas engine is high, the expansive force of the gases is correspondingly high, and is never completely utilised. The gases are always discharged into the atmosphere at a considerable pressure, which, had it been possible to prolong the stroke indefinitely, might be turned to useful account in doing work upon the piston. It is on account of this high expansive energy of the gases, that most modern writers insist upon ignition at the dead point. The whole heat is added, and explosion takes place as far as possible at constant volume, or before the piston has moved, and thus the whole volume of the cylinder is available for the expansion of the gases.

Engineers usually employ four kinds of Efficiencies, to represent the utilisation of heat and power in an engine.

I. The first is known as the Maximum Theoretical Efficiency of a perfect engine, and is defined in the preceding chapters. It is expressed by the formula, $\frac{T_1 - T_0}{T_1}$, and shows the working of a perfect engine between these limits of temperature ($T_1$ and $T_0$).

II. The second is the Actual Heat Efficiency, or the ratio of the heat turned into work to the total heat received by the engine.

III. The third is the ratio between the second (actual heat efficiency) and the first (maximum theoretical efficiency). It represents the maximum proportion of possible heat utilisation actually obtained by the engine.

IV. The fourth is the Mechanical Efficiency. It is the ratio between the useful horse-power (or brake H.P.) available at the end of the crank shaft, and the total indicated horse-power. The difference between the two is the I.H.P. necessary to drive the engine itself. Suppose an engine indicating a total of 100 H.P., and that by a special experiment it was found that 20 H.P. was required to keep the engine going at the same speed, without any external work. In such a case the mechani[illegible] efficiency would be 80 per cent. Examples of these imp[illegible] different efficiencies are given in Professor Capper's tests [illegible] also by Miller "On Efficiencies," and by other writers [illegible] subject.

**Ideal Diagram.**—The diagrams representing the ar[illegible]

in a heat engine are similar to that of Carnot's perfect cycle, but vary in shape according to the type of motor, and the curves produced by the pressure, expansion, and cooling of the gases. Fig. 101 represents a perfect cycle, in which the gases are compressed before ignition. The line A B is the abscissa, and is proportionate to the cylinder volume and the length of stroke. The line D F is the ordinate of pressure, and the mean height of the area D F B C D gives the mean pressure. Explosion takes place at D, the pressure rising instantly to F without change of volume, as the piston is stationary. From F to B the charge expands, and all the work of the engine is done. The pressure and temperature fall in consequence. From B to A the gases are discharged at atmospheric pressure. The piston draws in the charge from A to B and compresses it into the clearance space.

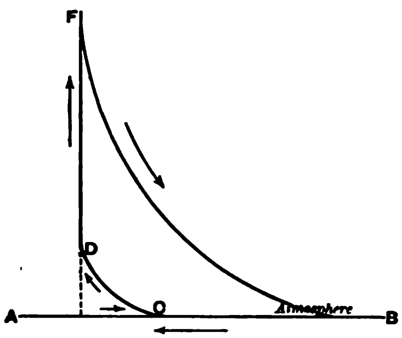


Fig. 101.—Diagram of Perfect Cycle with Compression.

In this ideal diagram all the lines follow Carnot's cycle. Compression and explosion are both adiabatic, that is to say, no heat is lost, but all is transformed into energy, and again refunded by compression of the charge. The gases also expand till their pressure falls to atmospheric, and their whole energy is supposed to be utilised. The diagram is formed of two adiabatic lines, compression and expansion; a vertical explosion line with no increase in volume during the rise in pressure, and a horizontal exhaust line, with no back pressure during the return to the original volume.

**Actual Otto Diagram.**—We will now consider what really takes place in an engine, and the area of work shown by an indicator diagram. Fig. 102 is an actual indicator diagram taken at a trial of an Otto engine by Messrs. Brooks & Steward, and similar to most modern diagrams. Here A B is the line of atmospheric pressure, and almost parallel with it is the line of admission, A C. It will be remembered that in the Otto cycle, the piston draws in the charge during one entire forward stroke. If the lines A B and A C be compared, the latter will be seen to be rather lower, showing that there is a small vacuum in the cylinder, and the charge is admitted at a pressure slightly below that of the atmosphere. From C to D the charge is compressed, the pressure rises, but the line falls below the adiabatic (compare C D in Fig. 101). Evidently the

heat is carried off and abstracted by the cooler walls, as well as stored up by the compression of the gas. From D to F is the explosion line, which also deviates from the perfectly vertical line in Fig. 101. The top of the diagram is rounded, showing that the piston had begun to move a little before explosion was complete; the pressure did not at once attain its maximum, nor was combustion complete when the highest pressure was reached. The line of expansion F G differs from the true theoretical adiabatic curve. Various circumstances, such as after combustion, and also the cooling action of the walls, contribute to

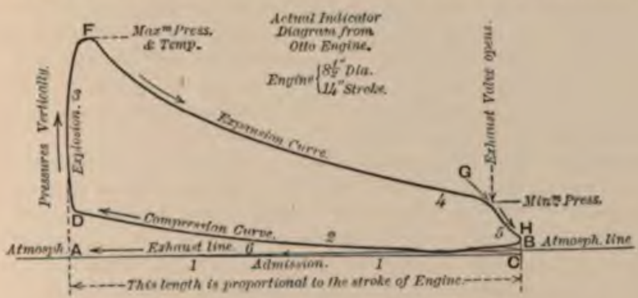


Fig. 102.—Otto Engine—Actual Indicator Diagram.
(The figures indicate sequence of operations.)

alter the shape of the expansion curve in actual gas engines. At G a phenomenon occurs, with which nothing in Fig. 101 corresponds. The exhaust valve opens prematurely, while the gases are still at a high temperature and tension, and the pressure falls suddenly, before expansion is completed; the gases escape into the atmosphere, instead of continuing to act upon the piston. At H the end of the stroke is reached, and the gases of combustion are discharged along the return line from H to A. At the beginning of the return stroke this line is above the atmospheric pressure to which the gases are in theory reduced at the end of expansion, and there is a certain amount of back pressure, or pressure retarding the motion of the piston.

This indicator diagram may be taken as a typical representation of the curves of pressure usually obtained in an Otto engine during two revolutions. The chief reasons for the variations in this, as compared with a theoretical, cycle, are:—

1. Explosion is not instantaneous, and continues [illegible] piston has begun to move out.

2. Combustion is not completed till [illegible] beginning of the stroke, and the whole [illegible] instantaneously.

3. Heat is carried off by the walls [illegible] reduce the temperature within practicable [illegible]

4. Expansion is never adiabatic, and the whole heat expended or evolved from the gas is not absorbed in doing work.

5. Expansion is not continued till the pressure of the gases is reduced to atmospheric, but they are discharged much before their full pressure has been utilised in work on the piston.

Although the formula $\frac{T_1 - T_0}{T_1}$ applies equally to all heat engines, there are various types of gas motors, each utilising differently the heat supplied. In practice they are classified under four heads. In each of these types the indicator diagram varies slightly in shape, and the actual efficiency may be expressed by a different formula. The formulæ of efficiency now generally used in calculating the work obtained in theory from a gas engine were originally drawn up by Professors Schöttler and Witz, and Mr. Dugald Clerk, from whose able generalisations the following figures are taken:—

**Formulæ for Efficiencies.**—The first three types of gas engines are direct acting, and the heat supplied acts directly by expansion of the gas upon the piston; the fourth is indirect acting, the expansion of the gases forces up the piston, but no work is done except during its descent. The formula for calculating the maximum theoretical efficiency is, as already given, $\frac{T_1 - T_0}{T_1}$, in which $T_1$ represents the highest absolute temperature attained by the gases, $T_0$ the temperature (absolute) to which they fall after doing work on the piston, and $1 - \frac{T_1 - T_0}{T_1}$ the percentage of heat utilised. The same formula may be differently stated, thus—

$$\frac{Q}{1 + n} = c_v (T_1 - T_0)$$

or—The total quantity of heat developed by the explosion of the gases (Q) divided by the weight of the charge (1 of gas plus $n$ dilution of air) is equal to the highest absolute temperature of the gases, $T_1$, less the lowest absolute temperature, $T_0$, multiplied by their specific heat at constant volume, $c_v$. The specific heat of the gases at constant volume is taken, because it is assumed that the whole of the heat is added before the piston has moved. From the quantities of heat the pressures can be deduced according to Boyle's law. Thus $p_1 = p_0 \frac{T_1}{T_0}$ or—The highest pressure, $p_1$ developed by the explosion of the gases is equal to the initial pressure, $p_0$ multiplied by the ratio between the highest lowest absolute temperatures. In the following formul pressures are omitted, but they can be worked out by the s from the temperatures.

1. The **first type** of gas motor is the direct-acting non-compression engine. Here the gases are not compressed before ignition, but are admitted into the cylinder at atmospheric pressure and ordinary temperature. All the heat is then generated at once, and the gases expand, driving the piston to the end of the stroke. The best example of this sequence of operations is furnished by the original Lenoir engine (see diagram, p. 35). In its cycle there are three important temperatures—$T_0$ the initial temperature of the gases admitted into the cylinder, $T_1$ the highest temperature during explosion, and $T_2$ the temperature of the gases at release, after they have done work on the piston. In theory $T_2$ should be equal to $T_0$—that is, the gases should be reduced to their original atmospheric temperature. In practice this is never possible, but they are always discharged at a higher temperature than $T_0$. Q represents the quantity of heat added from the source of heat (in heat units or calories), $Q_e$ the quantity discharged to the exhaust, $Q_c$ the quantity turned into work, and $\gamma$ the ratio between the specific heat of the gases at constant volume ($c_v$) and at constant pressure ($c_p$). Thus—

$$Q = c_v (T_1 - T_0).$$

The formula for actual efficiency E of this class of engine is :—

$$E = \frac{c_v (T_1 - T_0) - c_p (T_2 - T_0)}{c_v (T_1 - T_0)} = 1 - \gamma \left(\frac{T_2 - T_0}{T_1 - T_0}\right) = 1 - \frac{Q_e}{Q}$$
$$Q_c = Q - Q_e.$$

2. In the **second type** of engine the gases are compressed before ignition, and explosion takes place at constant volume. To the three temperatures given above, and always to be taken into account in estimating the heat efficiency of any engine, the compression of the gases before ignition adds a fourth, $T_3$ = temperature of compression. Work being done on the gas by driving the particles closer together, heat must be developed. This rise in temperature is calculated by multiplying the original temperature, $T_0$, by the difference in the volume of the gases before and after compression, raised to the power of the ratio of the specific heats minus 1. The temperatures are here obtained from the volumes, according to Boyle's law. The formula for calculating this temperature of compression is—

$$T_3 = T_0 \left(\frac{v_0}{v_1}\right)^{1{\cdot}408 - 1 = {\cdot}408,}$$

where $v_0$ is volume before compression, $v_1$ is volume after compression. The Otto four-cycle engine is the best example of this type (see [illegible]). Thus—

$$Q = [illegible] (T_1 - T_3) \qquad Q_c = Q - Q_e.$$

**The actual efficiency of this type is—**

$$E = \frac{c_v (T_1 - T_3) - c_p (T_2 - T_0)}{c_v (T_1 - T_3)} = 1 - \gamma \left( \frac{T_2 - T_0}{T_1 - T_3} \right) = 1 - \frac{Q_e}{Q}.$$

3. **The third type** represents an engine in which the gases are compressed before ignition, as in the second type, but instead of exploding, they burn at constant pressure. They enter the cylinder as flame, and drive the piston forward, not by the force of the explosion, as in the two former types, but by the expansion of the burning gases. It seems at first as though this type ought, in accordance with the theories hitherto laid down, to give a very low efficiency—that is, to utilise a very small proportion of the heat supplied to it, because there is a constant temperature of combustion during the forward stroke, instead of an instantaneous temperature of explosion. The highest temperature attained is not very great, and there is less range than in the other types. It is, however, an engine giving excellent results in theory, and it is difficult to understand why these results are not realised in practice. The working defects are attributed chiefly to insufficient compression. The efficiency depends, not on the highest temperature attained, but upon the amount of compression, and the greater the compression the greater the heat. In this class of engine, therefore, the usual rule is reversed, and an efficient cycle is obtained with a low temperature of explosion, $T_1$. The best example of this type is the Simon engine (see p. 53). In the formula the ratio of specific heat does not appear, because the burning gases are at a uniform temperature throughout the stroke, and all the operations are effected at constant pressure.

$$Q = c_p (T_1 - T_3) \qquad Q_e = c_p (T_2 - T_0) \qquad Q_c = Q - Q_e.$$

$$\text{Efficiency } E = \frac{c_p (T_1 - T_3) - c_p (T_2 - T_0)}{c_p (T_1 - T_3)} = 1 - \left( \frac{T_2 - T_0}{T_1 - T_3} \right) = E = \frac{Q_c}{Q}.$$

4. **Atmospheric Gas Engines.**—To this class belong engines in which the action of the gas upon the piston is indirect, and work is obtained, not by expansion, but by the formation of a vacuum under the piston. Theoretically, this type is the most perfect of all, because of the high explosion pressure, and the apparently unlimited expansion, but this great expansion can never be utilised in practice. A piston of undefined length, permitting the gases to expand until their pressure falls to atmosphere, would be necessary to utilise fully the power developed, and this is impossible under working conditions. As the gases are not previously compressed, there is no tempe— pression, but another temperature must be reck senting the temperature of the gases after opened, but before they are compressed by tl

restored to their original condition. The heat quantities are represented by—

$$Q = c_v\,(T_1 - T_0) \qquad Q_e = c_v\,(T_2 - T_4) \qquad Q_c = Q - Q_e$$

$$\text{Efficiency } E = 1 - \left(\frac{T_2 - T_4}{T_1 - T_0}\right) = \frac{Q_c}{Q}.$$

These formulæ will be best understood, if calculated and expressed in figures. The temperature of explosion in most gas engines is usually taken at from 1000° C. = 1273° Abs. to 1600° C. = 1873° Abs. The initial temperature is commonly assumed to be from about 12° C. = 285° Abs. to 18° C. = 291° Abs. The initial atmospheric pressure is taken at 14·7 lbs. per square inch; the volume of the cylinder is reckoned in cubic feet or cubic metres. In an experiment made on a 4 H.P. Otto engine by Dr. Slaby, the absolute temperatures were computed as follows:—

| | |
|---|---|
| Initial temperature, . . . . . . | $T_0$, 400° C. |
| Temperature of explosion, . . . . | $T_1$, 1504° C. |
| Temperature at the opening of exhaust, . | $T_2$, 1068° C. |
| Temperature of compression, . . . | $T_3$, 400° C. |

The actual efficiency calculated numerically (see formula of the second type) is—

$$E = \frac{0{\cdot}192\ (1504° - 400°)\ -\ 0{\cdot}264\ (1068° - 400°)}{0{\cdot}192\ (1504°\ -\ 400°)} = 1 - 1{\cdot}375\ \left(\frac{1068° - 400°}{1504° - 400°}\right)$$

or

$$E = \frac{211{\cdot}96 - 176{\cdot}35}{211{\cdot}96} = 0{\cdot}168 = 1 - 1{\cdot}375 \times {\cdot}605 = 17 \text{ per cent.}$$

From the above formulæ of efficiencies it is evident that, in order to obtain a sufficient fall in temperature, it is of great importance to keep the initial temperature of the gases low. In theory the efficiency of the engine depends on the range of temperature, and the lower the initial temperature, and the higher it can be raised by explosion the better. Much stress is therefore laid by all authorities upon introducing the gases into the cylinder at as low a temperature as possible. The utilisation of the heat in theory depends on the difference between the maximum temperature and the temperature of admission. In practice, however, the hotter the gases (after explosion), the greater will be the difference in temperature between them and the cylinder walls; consequently the waste will also be greater, because they will part with more heat to the water jacket. To obtain an economical work[illegible] cycle, all losses of heat should be [illegible] These are, the exposure of a large [illegible] gases, and length of time [illegible] causes to which waste of [illegible] next chapter.

The following table gives the heat balance of four different English engines, showing the quantity of heat developed, and the proportions of waste, and of useful work obtained. It is taken from Professor Kennedy's Trial of a Beck engine, and the Trials of the Society of Arts, 1889.

| | Beck. | Griffin. | Atkinson. | Otto-Crossley. |
|---|---|---|---|---|
| Heat developed per explosion, | 19,980 ft.-lbs. 100 % | 20,650 ft.-lbs. 100 % | 13,280 ft.-lbs. 100 % | ·34,040 ft.-lbs. 100 % |
| ,, converted into work, | 3,870 ,, ,, 19·4 % | 4,350 ,, ,, 21·1 % | 3,390 ,, ,, 25·5 % | 7,515 ,, ,, 22·1 % |
| ,, carried off in cooling jacket water, | 6,610 ,, ,, 33·0 % | 7,260 ,, ,, 35·2 % | 3,590 ,, ,, 27·0 % | 14,700 ,, ,, 43·2 % |
| ,, carried off at exhaust, | 8,570 ,, ,, 42·9 % | 8,220 ,, ,, 39·8 % | 5,030 ,, ,, 37·9 % | 12,100 ,, ,, 35·5 % |
| ,, unaccounted for, | 930 ,, ,, 4·7 % | 820 ,, ,, 3·9 % | 1,270 ,, ,, 9·6 % | ·8% over balance |
| Diameter of cylinder, | 7·5 inches. | 9·02 inches. | 9·5 inches. | 9·5 inches. |
| Stroke, | 15 ,, | 14 ,, | 12·43 ,, | 18 ,, |
| Number of revolutions, | 206·5 | 198 | 131 | 160 |
| Indicated horse-power, | 8·05 | 15·47 | 11·15 | 17·12 |
| Brake horse-power, | 6·31 | 12·51 | 9·48 | 14·74 |
| Mechanical efficiency, | 87 per cent. | 85 per cent. | 85 per cent. | 86 per cent. |

# CHAPTER XIX.

# EXPLOSION AND COMBUSTION IN A GAS ENGINE.



THE phenomena taking place and work obtained in a heat engine have now been shown to depend on the development and utilisation of heat. Since heat in the cylinder is obtained by the ignition, explosion, and combustion of a certain quantity of air and gas, the character of these phenomena, the strength of the explosion, and speed of propagation of the heat through the gas, are of the utmost importance. For many years they have engaged the attention of scientific men. By careful study and observation, a sufficient number of exact experimental facts have been accumulated to determine with precision the action of gas in an engine cylinder.

**Definition of Terms.**—Before proceeding to consider these phenomena, it will be well to define the different expressions generally used. Four terms are employed to denote the effects produced by heat in the cylinder of a gas engine—1, Ignition; 2, explosion; 3, inflammation; 4, combustion. Ignition takes place when sufficient heat is communicated by a flame, electric spark, or hot tube to the gaseous mixture to fire it. Inflammation is the subsequent spreading of the flame throughout the gas, or its propagation from one particle to another, till the whole volume is alight. Explosion follows when the mixture is completely inflamed, and the maximum pressure attained. When all the gas in a cylinder is thoroughly alight, the particles are driven widely apart, and thus the moment of complete inflammation will also be that of maximum pressure. Complete inflammation and explosion are thus practically simultaneous. Combustion is complete when all the chemical changes have taken place, and the gases have been reconstituted as water vapour ($H_2O$) and carbonic acid gas ($CO_2$). This moment may not coincide in point of time with explosion. The chemical recombination of the gase[illegible] and consequently the evolution of all the heat contained, is al[illegible]t always delayed in a gas engine [illegible]n of a second, after the [illegible]e piston has begun to

[illegible]sen.—It is at the

moment when explosion occurs that the maximum pressure is reached, and probably also the maximum temperature.* The importance of this temperature has been proved theoretically in the preceding chapter, and many experiments have been made to determine it, because it marks the rate of inflammation, or of propagation of the flame. The celebrated chemist, Bunsen, was the first to calculate the rate of flame propagation—or of inflammability—in a gas. He confined the mixture in a vessel having a very small orifice, and the gas was ignited as it passed out. The mouth of the orifice was reduced till the pressure of the issuing flame was exactly equal to that of the gas inside, and as soon as the balance of pressure was established, the flame spread back till it had ignited the gas in the vessel. The method of ignition used in the Koerting engine is somewhat similar. The rate at which the gas issued from the vessel being known, the speed of the flame, as propagated back through the mixture, was calculated from it. By these means Bunsen determined the velocity of propagation, or the inflammability of a gaseous flame. With a mixture of 2 volumes hydrogen and 1 volume oxygen, he found it to be 34 metres = 111·5 feet per second; with carbonic oxide it was 1 metre = 3·28 feet per second.

**Mallard and Le Chatelier.**—Later researches have shown that these figures are not accurate. The instrument then used could not be wholly relied on, because the external air cooled the flame as it issued from the orifice, and affected the results. A series of elaborate experiments have been conducted by MM. Mallard and Le Chatelier with a long tube filled with an explosive mixture, closed at one end, and communicating through the other with the open air. The period of explosion, or the time occupied by the flame in travelling through the tube, was marked by revolving drums and tuning forks, the latter being the best instruments for measuring, by their vibrations, fractions of a second. The drums revolved on the same shaft, close to either end of the tube, and a wavy line was traced upon them by the vibrations of the tuning forks, set in motion by the explosion. As soon as the gas at one end of the tube was ignited, it moved a small pencil, and marked the drum revolving at that end. A second pencil made a similar mark on the drum at the other end, when the flame had passed through the length of the tube. The distance between the two marks, measured on the vibrating line traced by the tuning forks, gave the time of propagation of the flame. With the same mixture of hydrogen and oxygen as that used by Bunsen, Mallard and Le Chatelier found the velocity to be 20 metres = 65·6 feet per second, and with

* Dr. Slaby says that "combustion is completely ended after a fractional portion of the stroke, from 0·03 to 0·06 of a second."—*Calorimetrische Untersuchungen*, p. 161.

carbonic oxide 2·2 metres = 7·2 feet per second, or a speed double that given by Bunsen.

These pure explosive mixtures are too strong to be used in a gas engine, as air is necessary to dilute the gas, and the mixture becomes immediately weakened with a large proportion of non-explosive nitrogen. MM. Mallard and Le Chatelier, therefore, varied the strength of the mixture. With 1 vol. hydrogen mixture (*i.e.*, 2 vols. hydrogen to 1 of oxygen) and 1 vol. oxygen, the rate of flame propagation was 10 metres = 32·8 feet per second. The highest velocity was found to be the mixture of 1 vol. hydrogen to 1 vol. oxygen, originally used by Bunsen, but to obtain a standard for the dilution commonly employed in a gas engine, the experimenters combined hydrogen with air in the proportion of 2 vols. hydrogen to 5 of air. The following table (from Clerk) shows the velocity of flame with hydrogen and various volumes of air:—

TABLE OF VELOCITY IN DILUTED MIXTURES (*Mallard and Le Chatelier*).

| | Velocity per Second. | Velocity per Second. |
|---|---|---|
| Mixture of 1 vol. hydrogen and 4 vols. air | 2 metres. | 6·5 feet. |
| ,, ,, ,, ,, 3 ,, | 2·8 ,, | 9·1 ,, |
| ,, ,, ,, ,, $2\frac{1}{3}$ ,, | 3·4 ,, | 11·1 ,, |
| ,, ,, ,, ,, $1\frac{6}{7}$ ,, | 4·1 ,, | 13·4 ,, |
| ,, ,, ,, ,, $1\frac{1}{2}$ ,, | 4·4 ,, *max.* | 14·4 ,, *max.* |
| ,, ,, ,, ,, 1 ,, | 3·8 ,, | 12·4 ,, |
| ,, ,, ,, ,, $\frac{1}{3}$ ,, | 2·3 ,, | 7·5 ,, |

In these experiments the explosive mixtures were at constant pressure; the end of the tube being open, the ignited gases issued from it in a continuous stream, and did external work against the pressure of the atmosphere. When both ends of the tube were closed, and the mixture was ignited at constant volume, the velocity with which the flame was propagated was very much greater. A speed of 1,000 metres = 3,280 feet per second, instead of 20 metres, was verified with hydrogen explosive mixture (2 vols. H and 1 vol. O). When the hydrogen was diluted with air, the speed was 300 metres = 984 feet per second. This great difference in the rate of flame propagation is attributed by MM. Mallard and Le Chatelier to inflammation taking place, not only by the projection of the flame from one particle to another, but by the expansion of the particles through the heat generated. As they ignite, they rise in temperature and pressure, and the propagation of the flame is thus assisted. When the mouth of the tube is closed, and the particles cannot expand freely into the atmosphere, the

ignited portions of the gas are forcibly projected into the parts not yet kindled. These experiments prove the greatly increased velocity of flame propagation when the volume of the gases is constant, and therefore the value of ignition at the dead point in a gas engine. The maximum explosive pressure is higher and more rapidly obtained, when the piston is stationary.

**Berthelot and Vieille.**—A series of valuable experiments were also carried out by MM. Berthelot and Vieille, to determine the rate of flame propagation (or of complete combustion, since in this case the two terms are synonymous) of gases at constant volume in a closed vessel. The time of explosion was determined in receivers of three different capacities—namely, 300, 1500, and 4,000 cubic centimetres. Two of the vessels were cylindrical and the third spherical, and each was fitted with a registering piston. At either end they terminated in a short tube; at the further end of one an electric spark was produced for firing the mixture, the other contained the piston. The lengths of the igniting tube, the cylinder, and the tube containing the piston being known, the time occupied by the flame in passing through the gas, from the point of ignition till the explosion reached and forced up the piston, could be calculated. The experiments were made with a variety of chemical compounds, such as bioxide of nitrogen, cyanogen, and compounds of hydrogen, oxygen, carbon, and nitrogen. The larger the capacity of the vessel or receiver, the longer time was found to elapse, with every mixture, between the ignition of the gas, and the attainment of maximum pressure. This agrees with Gay Lussac's law, since the smaller the vessel and the volume of the gas, the greater will be the increase in pressure produced by the high temperature of ignition. The effect of the composition of the mixture, and of the more or less perfect combustion obtained by adding oxygen in exact proportion or in excess, were also noted.

But one of the most important practical results of these experiments, with regard to the phenomena in a gas engine, was obtained with the products of combustion. By using a mixture of the chemical elements contained in these products, and observing the time occupied by the projection of the flame, MM. Berthelot and Vieille proved that the rate of flame propagation in such compounds was slower than with pure mixtures, representing the fresh charge of gas and air in a cylinder. Dilution with the products of exhaust, therefore, whether advantageous or not, must retard the rate of combustion, because these products contain an excess of some of the gases. With gases not perfectly combined, and where combustion is incomplete, the rate of flame propagation was found to be most rapid, perhaps because partial dissociation takes place and retards total combustion. MM. Berthelot and Vieille are of opinion that, by the ignition of the gas and the high temperature produced in the closed

vessel, what they term an "explosive wave" is formed, the velocity of which is greatly in excess of the ordinary velocity of flame propagation. They call it the rate of detonation. The explosive wave is generated by the shock of igniting a large portion of the inflammable gas at once; the flame is propagated with a velocity due to the shock, almost as great as the velocity of combustion. For hydrogen the velocity of this explosive wave is 2,810 metres = 9,216 feet per second; for carbonic oxide it is 1,689 metres = 5,539 feet per second.

Regarding the time of attainment of maximum pressure during explosion at constant volume, they say :—"The variations in this time are very important. The maximum pressure observed in a vessel of any given capacity is always less than the pressure which would be developed, if the system retained all the heat due to chemical reaction, for there is always a certain loss from contact with the walls and radiation. The smaller the quantity of gas in proportion to the vessel containing it, and the more slowly combustion takes place, the greater is this difference. The time occupied by combustion varies much; it corresponds to the different conditions developed at the beginning of the phenomena, and is intermediate between the velocity of the explosive wave, and the ordinary velocity of flame propagation of any given gas."

**Witz.**—Valuable as these theoretical determinations are in studying the theory of combustion, practical experiments are needed to calculate the actual result of generating heat in a gas, by combustion in an engine cylinder. With this object, Professor Witz undertook a number of valuable experiments to illustrate the action of ordinary lighting gas, when mixed with various proportions of air, and ignited. He also desired to show the influence of nitrogen in affecting injuriously the true rate of flame propagation. In MM. Berthelot and Vieille's experiments, the gas was always at constant volume, and no expansion was possible. M. Witz used an ordinary cylinder and piston, and the charge was allowed to expand freely. The first tests were made, not with lighting gas, which varied too much in composition to give accurate results, but with a mixture of carbonic oxide and air; the calorific value at given temperatures of each chemical element was previously determined. A basis being thus obtained for exact computation, lighting gas was used for the rest of the trials, and the differences in chemical composition neglected. Professor Witz attached a tuning fork to the indicator diagram, in order to measure, not only the pressure developed by the explosion, but the fractions of a second before the maximum pressure was attained. Taking the ratio of this [illegible] the length of stroke of the piston, he reckoned the speed [illegible] thus—

$$\frac{\text{[illegible] in feet}}{\text{[illegible]econds}} = \text{speed of expansion in feet per second}$$

Calculating the work done from the area of the diagrams, and its ratio to the theoretical work obtained from the number of calories in a given volume of gas and air, Professor Witz found that the percentage of work actually done increased in proportion to the speed of expansion. Some of the results of his able experiments made with lighting gas mixed with varying proportions of air, are summed up in the following table :—

EXPERIMENTS OF PROFESSOR WITZ ON TOWN GAS, WITH CONSTANT MIXTURE OF 1 VOLUME GAS TO 9·4 VOLUMES AIR.

[Vol. of mixture, 2·081 litres.]

| Duration of Explosion in Fractions of a Second, taken from Diagrams. *a.* | Length of Stroke of Piston. *b.* | Speed, Metres per Second. $\frac{b}{a} = c$ | Theoretical Work. *d.* | Work calculated from the Diagrams. *e.* | Utilisation or Per Cent. of Work done, Ratio of columns *d* and *e.* $\frac{e}{d}$ |
|---|---|---|---|---|---|
| Second. | Millimetres. | Metres. | Killogram-metres.* | Killogram-metres. | Per Cent. |
| 0·48 | 122 | 0·25 | 446 | 5·3 | 1·2 |
| 0·47 | 127 | 0·27 | 446 | 5·3 | 1·2 |
| 0·40 | 127 | 0·32 | 446 | 7·0 | 1·5 |
| 0·39 | 132 | 0·34 | 446 | 6·6 | 1·4 |
| 0·31 | 140 | 0·45 | 446 | 7·8 | 1·7 |
| 0·23 | 147 | 0·64 | 446 | 10·8 | 2·4 |

[1 Litre = 61·025 cub. ins.]

MIXTURE OF 1 VOLUME GAS TO 6·33 VOLUMES AIR.

[Vol. of mixture, 2·081 litres.]

| | | | | | |
|---|---|---|---|---|---|
| 0·15 | 259 | 1·7 | 633 | 17·6 | 2·7 |
| 0·09 | 259 | 2·9 | 633 | 40·1 | 6·2 |
| 0·06 | 259 | 4·3 | 633 | 50·5 | 7·9 |
| 0·06 | 259 | 4·8 | 633 | 50·7 | 9·3 |

In both these series of experiments the volume of the charge was the same—namely, 2·081 litres = 0·73 cubic foot. The richness of the mixture, the length of stroke, and the duration of the explosion varied. Fig. 103 shows a diagram of the expansion, with the vibrations below of the tuning fork used as a measure of time. Each vibration corresponds to $\frac{1}{128}$ of a second. The diagram gives the pressures and volumes, the lower waves mark the time occupied in expansion. The atmospheric line, H$x$, shows that expansion was continued to below atmospheric pressure. From these and many similar experiments, Professor Witz has formulated the two following laws concerning the expansion of gases :—

* Kilogrammetres mean kilogrammes × metres = 2·20 lbs. × 3·28 ft. or ft.-lbs. of work done (see p. 211).

I. The utilisation of the heat supplied to the engine increases with the speed of expansion.

II. The greater the speed of expansion, the more rapid will be the combustion of the explosive mixtures.

This speed of expansion, which the above table shows to have so important an effect on the proportion of actual to theoretical work, Professor Witz considers to be only the expression under another form of the great influence of the walls, and their cooling action upon the hot gases. "The maximum explosive pressure," he says, "depends on the ratio of the cooling surface of the receiver (or cylinder) to the volume of the gas." In his opinion, nearly all the differences between the action of the gases, in theory and in practice, in the cylinder of an engine, which have hitherto been so difficult to account for, may be attributed to the effect of the walls.

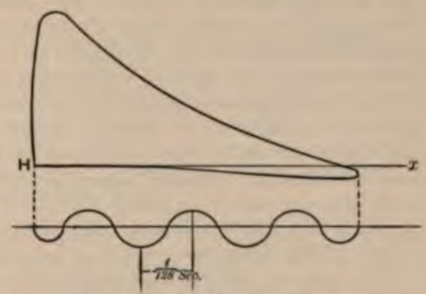

Fig. 103.—Witz' Time Diagram.

**Clerk.**—Mr. Dugald Clerk was led by his experiments to almost the same conclusions as Professor Witz, though he approached the subject from another point of view. He considered that, to understand the action of gas in a cylinder, it was necessary to determine not only its rate of explosion, that is, the time required to attain maximum pressure, but also the duration of this pressure. It is the force of the explosion which produces effective pressure on a piston. It seems therefore as if, the stronger the mixture employed within working limits, the more useful will be the effect, but experiments have shown this view to be erroneous. The greater amount of work is obtained, not from the most explosive mixture, but from that giving the maximum pressure in proportion to the surfaces, and maintaining that pressure during the longest period of the stroke. Since radiation cannot be prevented, the higher the explosive pressure and temperature generated, the more rapidly will the heat be carried off by the walls of the cylinder, and the pressure correspondingly reduced. This is one reason for the difference between theory and practice in an engine cylinder. Theoretically the highest explosive pressures are the best; but in practical working they are not found the most effective for power.

Mr. Clerk's experiments were made with a small cylinder without a piston, filled with different explosive mixtures, to which an indicator was connected. The indicator drum and paper were made to [illegible] tenth of a revolution occupied

0·033 second. The pressure of the explosive gases forced up the indicator pencil, causing it to trace different curves on the moving drum. By dividing the area of the drum into sections, the time occupied by the explosion, and cooling or reduction of pressure of the gases, could be estimated within $\frac{1}{100}$ of a second. On this diagram the ordinates represented pressures, as usual, and the abscissæ the time of explosion in fractions of a second. The conditions under which gases explode in the cylinder of an engine were reproduced in all but two respects. Under ordinary circumstances the piston in a gas engine uncovers during the stroke fresh portions of the cooler walls to the hot gases, and the explosive pressure is rapidly lowered. Here the maximum explosive pressure was developed in a closed vessel, and, therefore, at constant volume; and the cylinder having no piston, no heat was expended in doing work. The conditions were similar to those of an engine before the piston has moved.

Mr. Clerk gives several diagrams showing that the pressures of the gases fell much more slowly than they rose. The maximum pressure was produced in 0·026 second after ignition; the fall to atmospheric pressure and temperature occupied 1·5 second, or nearly sixty times as long. Without previous compression of the gases, the highest pressure obtainable with a dilution of 1 part gas to 5 parts air (that is, the mixture containing just enough oxygen to produce combustion of the gas) was only 96 lbs. per square inch. With compression and a much weaker mixture, this pressure was nearly doubled. Mr. Clerk proved that the "critical mixture," or the weakest dilution of gas and air that will ignite, varied according to the quality of the gas used. With Oldham gas a charge of 1 part gas to 15 of air ignited, and the pressure produced was 40 lbs. per square inch above atmosphere. With Glasgow gas the critical mixture was 14 of air to 1 of gas, and the pressure produced was 52 lbs. per square inch.

To determine the best and most serviceable mixture for use in a non-compressing gas engine, the following calculations were made. Mr. Clerk supposed 1 cubic inch of gas to be diluted with air in the ratio of 13, 11, 9, 7, and 5 cubic inches, and these mixtures to be admitted into cylinders having pistons, the areas of which per square inch were in proportion to the strength of the dilution. Thus the charge of 14 cubic inches—viz., 1 volume gas to 13 volumes air—would be admitted into the cylinder having a piston surface of 14 square inches. The mixture of 6 cubic inches would be contained in the cylinder having a square piston area of 6 inches, and the depth of the mixture i[illegible] the cylinder would always be 1 inch. The maximum press[illegible] of these mixtures he had already determined, as well as t[illegible] time of explosion, by the instrument mentioned as shown in following table :—

EXPERIMENTS BY MR. CLERK ON EXPLOSION AT CONSTANT VOLUME IN A CLOSED VESSEL WITHOUT PISTON. MIXTURES OF AIR AND GLASGOW COAL GAS.

| Mixtures used. Gas. | Air. | Maximum Pressure above Atmosphere in lbs. per sq. inch. | Time of Explosion, or time elapsing between Ignition and Maximum Pressure. |
|---|---|---|---|
| 1 volume plus | 13 volumes, . | 52 lbs. | 0·28 second. |
| 1 ,, ,, | 11 ,, . | 63 ,, | 0·18 ,, |
| 1 ,, ,, | 9 ,, . | 69 ,, | 0·13 ,, |
| 1 ,, ,, | 7 ,, . | 89 ,, | 0·07 ,, |
| 1 ,, ,, | 5 ,, . | 96 ,, | 0·05 ,, |

Temperature before explosion, 18° C. = 291° Abs. Pressure before explosion, atmospheric.

By these and other experiments Mr. Clerk found that the highest pressures, giving respectively 756 lbs. and 728 lbs. upon the total piston area, were obtained with a dilution of 11 and 13 volumes of air to 1 of gas. The stronger mixtures gave lower pressures, because, being contained in smaller cylinders, the pressure, to a uniform depth of 1 inch, was exerted over a smaller piston surface. The rate of cooling, or of fall in pressure, was calculated in the same way. Taking one-fifth of a second as the mean time occupied by the piston in making its forward stroke, the pressure of each gas when that time had elapsed, after the attainment of maximum pressure, was computed from the indicator diagram. Multiplying this pressure by the piston area, it was found that the weakest mixtures gave the highest relative pressure at this point in the stroke, showing that these weak mixtures maintained their pressure longest. The following table exhibits the results for five different dilutions :—

EXPERIMENTS BY MR. CLERK ON MIXTURES OF AIR AND GLASGOW GAS AT CONSTANT VOLUME (*with same Apparatus*).

| Mixture. | Pressure produced on piston by 1 cub. in. gas. | Pressure in lbs. per sq. in., 0·20 second after max. press. | Pressure remaining upon piston area 0·20 sec. after max. pressure. | Mean Pressure. |
|---|---|---|---|---|
| 1 vol. gas plus 13 vols. air | 728 lbs. | 43 lbs. | 602 lbs. | 665 lbs. |
| 1 ,, ,, 11 ,, | 756 ,, | 48 ,, | 576 ,, | 666 ,, |
| 1 ,, ,, 9 ,, | 690 ,, | 47 ,, | 470 ,, | 580 ,, |
| 1 ,, ,, 7 ,, | 712 ,, | 55 ,, | 440 ,, | 576 ,, |
| 1 ,, ,, 5 ,, | 576 ,, | 57 ,, | 342 ,, | 459 ,, |

Mr. Clerk also [illegible] with pure hydrogen diluted with air, but [illegible] lower than with gas.

The best mixture, 1 volume hydrogen to 5 volumes air, gave a mean pressure of only 267 lbs. upon a piston of proportionate area, one-fifth of a second after explosion. For further details of these interesting experiments, the student is referred to Mr. Clerk's excellent book *The Gas Engine*, pp. 95 to 104.

**Wall Action in Gas Engine Cylinders.**—All these researches tend to show that the causes of loss of heat, and consequent waste of heat energy, depend largely upon the total internal area of the cylinder exposed to the gaseous mixture. The less this area for a given cylinder volume, the higher will be the pressure. Therefore, the more the action of the walls can be diminished during the development of the heat, the more certain and rapid will be the explosion, and the greater the pressure of the gas. This result can be obtained in three ways, by reducing—

1. The time during which the wall action continues.
2. Its intensity.
3. The proportion of area of the walls to the volume of the gases.

1. Opinions vary greatly as to the advantage of high piston speeds in gas engines, but the tendency of modern engineers is, in the main, to increase speed within reasonable limits. Beyond about 300 revolutions per minute, M. Richard considers that the friction and heat developed are too great to work an engine continuously, and if much heat is generated by explosion, a correspondingly large amount is discharged at exhaust. Within certain limits, however, high speeds are advantageous, because the colder walls have less time to act upon the hotter gases, and carry off their heat. The same arguments show the value of ignition at the dead point. The piston having reached the end of its return stroke, and exhausted some of its energy of motion, does not move at the required velocity until driven out again. Explosion being practically completed before the volume of the cylinder is enlarged by the out stroke of the piston, the cooler walls have not much time to diminish the high temperature of the gases produced by explosion, and reduce the pressure before it can act on the piston. The rapid expansion so much insisted on by Professor Witz has the same effect, in diminishing the wall action. The more rapidly the walls are uncovered, the less time is allowed them to act on the gases, and carry off the heat. At the same time rapid and complete expansion does not always mean a proportionate utilisation of the heat supplied to the engine. M. Richard shows by the figures given in the Society of Arts' Trials that in the Atkinson engine, where expansion is greater in proportion to admission and compression, the heat carried off by the walls, that is, during the expansion stroke, is relatively small, but more is discharged into the exhaust than in engines having a less expansion. If the two items of heat expenditure be added together (see table, p. 242), they will be

found almost the same as in the Otto engine tested at the same time.

2. To diminish this great action of the walls, and to equalise their temperature and that of the gases, it is necessary to raise the temperature of the one, or lower that of the other. To raise the temperature of the walls is impossible, without injury to the engine. But by diluting the charge of gas with air to the limit of inflammability, and by utilising the inert gases, the heat of explosion may be diminished, without affecting the efficiency of the engine. This diminution of the maximum temperature is the reason of the comparatively high efficiency obtained in practice, with engines having combustion at constant pressure. As there is no very sudden rise in temperature, less heat is carried off by the walls, and more remains to do work on the piston.

3. The third is perhaps the greatest source of waste of heat in the engine cylinder. The most effectual method of diminishing the wall action is by previous compression of the charge. In M. Richard's opinion it is only by this means that the losses of heat can be sensibly reduced, because compression diminishes the volume of the gases exposed to the cooling influences of the walls. Other conditions being equal, the larger the cylinder, the smaller will be the loss to the walls, because the smaller their area relative to the volume of the gases. As a result, less heat will be lost per cubic foot of gas to the walls and water jacket.

**Loss of Heat.**—But however carefully an engine may be designed, to keep the temperature and pressure of the charge within practical limits, all authorities are agreed that the greater part of the heat in a gas motor is lost by radiation and conduction, or discharged at exhaust. These are the two great sources of waste. If the heat accounts of the four engines given at p. 242 be compared, it will be seen that the jacket water and the exhaust carried off between them from 65 to 75 per cent. of the total heat developed. In the opinion of so competent an authority as M. Richard this waste cannot, in our present state of knowledge, be avoided. The heat economised from the one is usually wasted to the other. If the losses from the walls be diminished, the heat of the exhaust gases is increased. Nor is it possible at present to prevent the loss to the jacket to any great extent.

Notwithstanding every effort to determine the right mixture of gas and air, and to obtain complete combustion, as far as possible, the actual pressure in a gas engine is seldom more than about half the calculated. As pressure is always in strict proportion to heat, this deficiency, shown by the indicator diagrams, proves that much of the heat contained in the chemical constituents of the gas, and which ought to be liberated by their com bination with oxygen during combustion, is either carried o not evolved. If all the heat were developed at the mome

explosion, and expended in doing work on the piston, the curve representing the expansion of the gases would be adiabatic. The line of expansion would follow the theoretical line of Carnot's cycle, and exhibit heat neither added nor abstracted, but solely employed in doing work. That this does not take place in practice can be seen, by comparing theoretical with actual diagrams. The difference between them is considerable. The line indicating the decrease in temperatures consequent on expansion is much higher in the theoretical than in the actual diagrams.

**Variations in Expansion Curve.**—The Otto diagram at p. 237 shows a peculiarity in the pressures obtained in the cylinder of later compression engines, which has not hitherto been satisfactorily explained. The fall of the expansion curve in the theoretical is, as we have said, more rapid than in an actual diagram. This theoretical curve represents exactly the fall in pressure, and therefore in temperature, which would be obtained, if the gases expended their heat entirely in doing work. If the curve of the actual diagram is flatter, and does not fall so rapidly, this difference shows that the pressure does not in practice sink so quickly, and heat is not parted with as speedily as in theory. The law of the mechanical equivalent proves that the amount of heat expended in doing work does not vary, but is always the same, in practice as in theory. If, therefore, the pressure and temperature do not fall so rapidly in an actual engine, heat is added in some way. This addition of heat is obtained either from within or from without. Most authorities maintain that it is evolved from the mixture itself, because the walls of the cylinder, cooled by the water jacket, must always be at a lower temperature than the gases they enclose, and cannot convey heat to them. In considering the difference between inflammation and combustion, it has been shown that the moment of maximum explosion or pressure does not always agree with that of complete combustion. The two operations are not simultaneous. The gases may reach their maximum pressure, and the particles be driven widely apart by the flame spreading through them, before their perfect combination with the oxygen of the air, and reconstitution as $CO_2$ (carbonic acid) and $H_2O$ (water vapour). This is the phenomenon which is now acknowledged by most scientific men to take place in the cylinder of a gas engine, and to cause the addition of heat shown in the slow fall of the expansion curve. The gases continue to re-combine and evolve heat after the period of maximum inflammation and pressure, and while the piston has already begun to move out by the force of the explosion. This chemical action is faithfully reproduced in the indicator diagram.

**Equilibrium of Heat.**—It is generally admitted that, in the cylinders of almost all direct-acting engines, with explosion at constant volume, this "equilibrium of heat," as it has been called, takes place. Heat is suppressed at the maximum temperature

of explosion, to be evolved afterwards, during the expansion stroke. In many gas engines the expansion curve falls rather more rapidly than in the Otto diagram at p. 237. Even then, however, so much heat is carried off by the walls, that there could be no approximation to adiabatic expansion, unless heat were in some way added, to counteract the wall cooling effect. The phenomenon is described in German by the expressive term "nachbrennen." In English it is called "slow combustion," but it would be more correct to term it "after combustion." The fact is now well established, but the causes of this "after combustion" of the gases are still uncertain, and the following theories have been advanced to account for it.

**Stratification.**—The first was put forward by Otto, because it was in the diagrams of his engines that the effect of this "after combustion" upon the expansion curve was first studied. He claimed it as a direct result of the stratification of the charge, one of the improvements specified in his patent of 1876. Instead of admitting the gas and air together through valves, as in later engines, the admission ports of the Otto were so arranged, that the air entered first. The gas valve then slowly opened, and the air was diluted with gas, the mixture increasing in percentage of gas as it continued to enter the cylinder until, the air port closing, nothing but gas was finally admitted. The products of combustion were not expelled from the cylinder, but remained and combined with the air in front of the fresh charge, to form a sort of cushion between the richer mixture and the piston, and to deaden the shock of the explosion. Thus between the piston and the ignition port there were—1, Products of combustion. 2, Pure air. 3, Air diluted with gas. 4, Gas only. According to Otto, combustion is very rapid at first through the explosive charge nearest the admission port. It spreads more slowly through the poorer mixture, because of its greater dilution with air, and with the products of the former charge (which MM. Berthelot and Vieille's experiments have proved to retard combustion), and hence the whole heat is not developed at once. Not only did Otto recognise the existence of the phenomenon of "after combustion," but he endeavoured to utilise it. In his opinion, this chemical burning process was under control, and might be produced at will, and turned to advantage by stratification of the charge.

This theory was supported by experiments made on an engine at the Otto Deutzer Gas-Fabrik. A glass chamber or prolongation was added to the cylinder of the engine at the admission end, and cigarette smoke was introduced into it by the momentary opening of a cock, [illegible] the piston was at the inner dead point. The movem[illegible] could be watched through the glass. Instead [illegible] the cylinder and impinging against the pis[illegible] admission

cock, and only the back part of the cylinder was filled with it, even after the crank had made several revolutions. Some however were not convinced by this experiment that the admission of the mixture into the cylinder could be regulated at will, and other trials were made on a 4 H.P. engine by Professors Schöttler, Teichmann, and Lewicki, to determine whether stratification of the charge actually existed or not. In these, admission was effected as usual through an ordinary slide valve. Ignition took place at the back of the cylinder, but there was also a special arrangement, by means of which the charge could be ignited at the side only, behind the piston, and in front of the compression space. As long as the ordinary ignition at the further end was used, indicator diagrams were obtained, similar to the one at p. 237. But when the mixture was ignited at the side, the brake horse-power, representing the work actually done by the engine, sank to half the normal power, and the diagrams showed a great diminution in the pressure, and retardation in the time of maximum explosion. The ignitions obtained were uncertain, often failed entirely, and were always too late. Analyses of the gases, taken from different parts of the cylinder, were also made by Professors Dewar and Teichmann, and it was found, as might have been expected, that their chemical composition in the lighting port, at the end furthest from the piston, was much richer than in front of the compression space. With a strong mixture, Teichmann found that the charge contained 16·2 per cent. of rich gas in the igniting port, 13·3 per cent. in the centre of the compression space, and 9·1 per cent. close to the piston.

The theory that stratification of the charge, which these experiments were undertaken to prove, caused the effects of after combustion has now been abandoned. Professor Schöttler and other scientific observers have pointed out that smoke cannot be considered as fairly representing the gaseous charge in the cylinder of an engine. Nor does it always remain at the back of the cylinder; in experiments undertaken by him on a Koerting engine, the whole cylinder was filled with a cloud of smoke. That ignition at the side proves stratification of the charge has also been disputed. It shows that the mixture is richer in some parts than in others, which might naturally be inferred under any conditions, but not that the gas remains in layers after introduction, although such a disposition is imparted to it at first. In experiments made on a Benz engine, under the same working conditions as the Otto, this partial stratification was not found to exist, and the charge was ignited with equal certainty at various parts of the cylinder. The latest authorities on the subject maintain that stratification cannot be preserved, even if the gases enter the cylinder in successive layers of richness, because of the compressive and

mixing power exerted by the back stroke of the piston. It is impossible, they say, to conceive that the charge can adhere to the original order of its admission, when the rapidity with which the piston compresses it is considered, and even if stratification were proved, it is not sufficient to explain "after combustion."

M. Richard is, however, of opinion that there is an evident gain in efficiency if the products of combustion remain in the cylinder, although the actual stratification is not preserved. In the first place, to retain the burnt gases does not weaken the succeeding explosion if care be taken, as in the Otto engine, that the richest part of the mixture lies round the ignition port. Without any attempt at regular stratification, the products of combustion will naturally be disposed round the piston, and act as a cushion to deaden the shock of explosion. Again, these inert gases are at a high temperature, and if they be left in the cylinder, instead of being carried off to the exhaust, more heat remains to increase the pressure and expansion, and less is discharged.

**Dissociation.**—The next theory to account for the phenomenon of "after combustion" has been advanced by Mr. Dugald Clerk. He attributes it to the chemical action known as "dissociation." At certain high temperatures chemical compounds decompose, or separate into their constituent elements, and do not recombine until the temperature has fallen. Thus heat, which is one of the great forces in combining chemical elements, is also a powerful agency in splitting up compounds. The existence of this phenomenon has been repeatedly verified. Without it, it would be possible, during the combustion of gases, to reach much higher temperatures than have ever been attained in practice. If, for instance, steam be raised to a very high temperature, it ceases to be steam, and decomposes into its elements of oxygen and hydrogen. The higher the temperature, the more complete the dissociation, until a point is reached, above which all gases exist only as primary elements. The temperatures of compound gases, therefore, are probably limited, though the extent of this limitation has not yet been determined. Without dissociation it should be possible in theory to raise the temperature of hydrogen burning in oxygen to 9000° C., but no experiments have, to the author's knowledge, been made, in which a temperature of 3800° C. has been exceeded. Clerk maintains that, at the temperatures produced in a gas engine dissociation takes place, and checks the further development of heat. The gases decompose, their heat is suppressed, and not evolved until, the temperature being lowered by expansion, the chemical elements are able to recombine. If dissociation [illegible] the cylinder of a gas engine, its action would [illegible] by Mr. Clerk. Most scientific men, however, [illegible] that the estimate of

temperature on which the theory is based is incorrect. Mr. Clerk, following Déville, is of opinion that dissociation commences at a temperature of from 1,000° C. to 1,200° C. Since the results of his researches were published, it has been proved by the experiments of Mallard and Le Chatelier and others, that dissociation takes place at much higher temperatures than those in a gas engine cylinder. For carbonic acid it is perceptible at 1,800° C. and is less than 5 per cent. at 2,000°, but with steam, dissociation only appears at a temperature above 2,500° C. and at 3,300° C. it is still very slight. The highest temperature in a gas engine is probably never above 1,870° C. Abs. It is impossible, therefore, to account for the phenomenon of "after combustion" by the theory of dissociation.

**Cooling Action of Walls.**—Professor Witz has advanced another theory to explain it, and supports his view with the weight of his scientific reputation and experience. He attributes the variation of temperature shown in the slow fall of the expansion curve, and the suppression and retarded evolution of heat, entirely to the cooling action of the cylinder walls. To this he refers all the phenomena hitherto obscure in the cylinder of a gas engine. He is of opinion that this cooling effect has been neglected hitherto, and that, next to the charge itself, the walls play the most important part in the cycle of an engine. By carrying off the heat generated at the moment of explosion, they instantly diminish the temperature. Although continually cooled by the jacket, they act as reservoirs, and actually restore to the gas, during the latter part of the stroke, some of the heat they had previously absorbed.* In the earlier gas engines, without compression or ignition at the dead point, and with a much smaller range of temperature, the effect of the walls, though ignored, was very great. In modern engines this effect is greatly restricted, with the result, according to Witz, that the walls are able to refund heat to the gas during the expansion stroke.

Professor Schöttler agrees with Witz as to the marked effect produced by the walls. He is of opinion that the phenomenon of "nachbrennen" may be in part attributed to heat actually restored by the walls, and specially by the piston, to the hot gases. He suggests that the heat evolved by the combination of the chemical elements is transmitted, at the moment of its development, through the walls to the water, and that there is a fraction of a second during combustion when the temperature of the walls is actually higher than that of the gases they enclose. The effect would be the continued development of heat along the expansion line, after the attainment of maximum pressure.

* The opinions of Professor Witz here given touch, in the author's opinion, upon debateable ground.

**Increase of Specific Heats.**—A fourth solution of the problem has been suggested by MM. Mallard and Le Chatelier. From various experiments they have made, they are of opinion that the specific heats of gases increase at very high temperatures, and that this increase may in part account for "after combustion." The subject is still in the stage of investigation, and no very positive determinations have, we believe, yet been made.

Whatever the causes producing the phenomenon of "nach brennen," there can be no doubt that it is in itself injurious, and not, as Otto considered, advantageous. The suppressed heat, although ultimately developed, is not evolved at the right time, and therefore cannot contribute to the maximum pressure of explosion. In practice and in theory the full utilisation of the heat supplied to an engine depends on the range—that is, the maximum temperature of explosion, and the minimum temperature of exhaust. Whatever checks the attainment of this maximum temperature has an injurious effect on the efficiency of the engine. The difficulties of the subject have been ably summed up by M. Richard in the following words:—

**Cylinder Wall Action.**—"No satisfactory answer has yet been found to the question: What is the cause of the loss of heat during explosion and expansion? It cannot be denied that it is partly caused by the action of the walls; they have an influence which, if studied alone, may almost be formulated as a law. But is the effect of the walls varying or constant? To what extent does it intervene, during the motor stroke, in the other phenomena? These are,—the increase of specific heat at the temperature of explosion (not yet universally admitted);—dissociation, a phenomenon rather suspected than proved;—combustion continuing during expansion, which some deny and others vehemently affirm. If it exists, as in my opinion it does, it is a result of the composition of the charge, compression, and the method of ignition. In a word, it is a most complex phenomenon, not only in itself, but because it is connected with all the actions simultaneously produced during the short period of a motor stroke. . . . The experimental theory of the gas engine has not yet been made. . . . Like that of the steam engine it cannot be determined without experiments, but it is of such importance that it ought to be undertaken, without shrinking from the toil and difficulty, the length and cost of the study it involves."

The Author is of opinion that the cylinder wall action in gas, as in steam engines, is very considerable, and it may be well to compare this action in the two types of motors. In the case of a single-acting horizontal four-cycle gas engine with water jacket, the difference of temperature between the gas and the metal is greater than between the steam and the metal in a steam engine. In gas engines heat goes through the metal walls nearly always

in one direction, from the centre of the cylinder outwards. There is a greater flow of heat at the explosion end of the cylinder and in the large clearance areas, because the temperature and pressure are greater than at the other non-explosion end. During the three non-motor strokes, the heat would travel through the walls much less rapidly, and the temperature of the metal would tend to become uniform. In a steam engine the wall action fluctuates periodically in the thickness of the metal, first in one direction, then in the other. During the steam stroke, heat passes from the hot steam to the cooler walls, and during the exhaust, from the hotter walls in the reverse direction.

In a gas engine, during the explosion and expansion stroke, the heat passes rapidly doubtless from the hot gases to the cooler walls, which, on the side touched by the water, are at a temperature of say about 150° to 180° F. The temperature of the gases will vary from say 1,800° to 2,500° F. If we assume an average of 2,000° F., there will be a difference of temperature of about $2{,}000° - 150° = 1{,}850°$ F. between the gases and the metal next the water, causing the heat to flow through the walls to the cooler circulating water.

During the exhaust stroke the gases are still much hotter than the walls, and the heat flow will be in the same direction, but less energetic. During the admission stroke of cold gas and air, the movement of heat will either be reversed or nearly suspended, as, by the time the charge has actually filled the hot cylinder and clearance, there will no doubt be little difference in temperature between it and the walls. During the compression stroke, there will be a tendency for the heat to pass again to the walls from the gases. We may thus assume that the flow of heat, though varying much in intensity, is generally from the internal to the external surfaces of the cast-iron walls, or from the hot gases to the cooler water.

At the explosion end of the cylinder the clearance surfaces will, to the thickness perhaps of a sheet of paper, approximate to the temperature of the dry gases. The lubricating oil will act as a non-conducting film, and tend to check the flow of heat. Nor must it be forgotten that, according to the opinion of the best authorities, the centre of the charge is much hotter than the parts in contact with the walls. The flow of heat may, therefore, commence from a hot nucleus in the middle of the cylinder. The thickness of the metal walls will vary say in different sized engine cylinders, from 1 to 1½ inch. As the metal at the explosion end will be much hotter than at the other end, there will probably be a flow of heat horizontally through the thickness of the wall towards the crank, as well as the flow radially from the hot gases. These two movements of heat will probably form a thermal gradient slightly inclined to the axis of the cylinder.

**Effect of Time.**—Again, there is the question of time influ-

encing the wall heat action. Taking two motors running at different revolutions per minute, the engine with the slower piston speed will give the water and the gases more time to interchange their heat than the quicker running engine, in which a shorter time per stroke is allowed. The quantity of jacket water passing per minute round the cylinder, to cool so many square feet of internal surface, is another factor of this complicated wall action. In other words, the number of lbs. of water passing per minute through the jacket per square foot of internal surface should always be considered, as well as the action of the metal of the piston. As the clearance area exposed to the hot gases is much larger in gas than in steam engines, these important surfaces should, in accurate experiments, be given in square feet, as well as the cylinder volume. During the different strokes violent movements will take place inside the cylinder, particularly during the explosion stroke, when the whole cylinder is probably filled with flame.

M. Richard maintains rightly that experiments are much needed to determine the temperature of gas engine walls, of which so little is known. The author hopes soon to be able to make some tests similar to those he has undertaken upon steam engine walls, where the temperature of the cast-iron cylinder plays a most important part.

Professor Kennedy shares the opinions of most other scientific men as to the great future possibilities of the gas engine. In a lecture delivered at the Royal Institution (in April, 1893), on the "Utilisation of Energy," he places the theoretical efficiency of coal gas at 80 per cent. Of this a gas engine, he says, utilises from 22 to 32 per cent. The waste of heat is chiefly due to the jacket, because, owing to the high temperature of the working agent, we have, in Professor Kennedy's words, to "adopt the somewhat barbarous expedient of continually keeping the metal cool by means of a water jacket."

# PART II.

# PETROLEUM ENGINES.

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## CHAPTER I.

## THE DISCOVERY, UTILISATION, AND PROPERTIES OF OIL.

CONTENTS.—Petroleum; Its Production in Russia, America, and Scotland —Composition — Distillation — Density — Flashing Point — Evaporation —Pressure—Utilisation of Oil—As Liquid Fuel on Railways, &c.—Oil Gas—Mansfield Producer—Keith—Rogers—Pintsch.

THE name petroleum, or rock oil, is derived from the Latin words *petra*, a rock, and *oleum*, oil. It is a mineral product, obtained from the earth in two different ways. Most of the oil used is drawn, at varying depths, from subterranean wells in a natural state, but a relatively small quantity is also produced by distillation from bituminous shale. The extraction of oil has been carried on in Scotland since 1850; the discovery of rock oil in the earth, and the operations necessary for bringing it to the surface, date from a few years later. A third kind of oil, which must be distinguished from these, is obtained from fat and grease, by the application of intense heat, in retorts. The process is usually continued until the oil has been converted into a rich gas. Lastly, there are vegetable oils, such as linseed, castor, palm, or olive oil, from which gas may also be produced by distillation. To distil gas from any kind of oil, great heat is necessary.

**Petroleum.**—Within the last few years petroleum has become a most important article of commerce. There are two countries from which this oil has been chiefly obtained, the shores of the Caspian Sea, and the centre of the United States. It is known, [illegible]ever, to exist in many other places, and has been found in [illegible]h America, especially in Peru and the Argentine Republic, [illegible] (1890), Beloochistan, Japan, China, Burmah, [illegible], and in the south-east of Europe. Some [illegible] of opinion that petroleum may be discovered [illegible] the borings are carried deep enough into the

earth. But for the present the supply from Russia is, and will probably long continue to be, practically unlimited, and Russian petroleum is conveyed so cheaply all over Europe, that it is not worth while to seek for oil elsewhere. The chief centre of the oil industry is round the shores of the Caspian, though important oil fields have been discovered in Central Asia. It is only within the last twenty years that these vast natural reservoirs have been utilised, and their discovery threatens in several ways to revolutionise commerce, especially as providing a new kind of fuel. The town of Baku, the capital of the Caspian district, has from a village become a large and flourishing city, since oil has been found in great quantity in its vicinity. The existence of an oil region round the Caspian was known from the earliest times. The district was called by the ancients the Fire Region, and the mysterious flames which issued from fissures in the rocks were worshipped by them 600 years B.C., as manifestations of the Fire God. These flames are nothing more than the gases given off by the subterranean oil reservoirs, ignited at some remote period, and which have never been extinguished.

**Russian Oil.**—The extraction of oil from the earth in the Baku district is now carried out on a regular system. The wells are tapped, or the oil is "struck," as it is called, and immediately rises to the surface at a high pressure. It is then conveyed through pipes direct to the refineries, where it is purified, and separated into the lighter volatile oils, as naphtha, the lighting or intermediate oils, lubricating oils, which are all of varying density, and the crude petroleum called "astatki." Through another line of pipes it is next carried to fill the tanks in the steamers on the Caspian, no other method of distribution being employed. This system of pipes forms a network over an area of several square miles round Baku, and the oil issues from the wells at so high a pressure that no pumping is required, until the flow has begun to diminish. It is struck at a depth varying from 70 to 825 feet below the surface. A new line of pipes is now in course of construction, for carrying refined oil from Baku through the Caucasus to Batoum, on the Black Sea, 560 miles distant, from whence it will be easy to convey it by sea to the south of Russia, and throughout the countries bordering on the Mediterranean. The oil industry of Baku has been greatly developed, and almost created by two Swedish engineers, Robert and Ludwig Nobel, who have organised a system of obtaining and refining the oil, and distributing it all over Europe (see Note on p. 334.)

**American Oil.**—The second source of oil supply is from Pennsylvania and the Alleghany district in North America, and the newly discovered oil regions of Athabasca in Central Canada. Here also the supply is ample, though the borings are carried much lower, oil being usually found at a depth of from 500 to

4,000 feet from the surface. The petroleum wells of Pennsylvania were discovered about 1859. The oil issues from the ground at a lower pressure than in the Caspian district, and is pumped through pipes, often hundreds of miles in length, to the chief commercial centres of the United States. There are about 25,000 petroleum wells in America, and 400 in the Caspian, but the supply in the latter is very much more abundant. In 1890 the yield of oil from the American wells was 2,600,000 gallons a day, and from the Caspian nearly 2,700,000 gallons per day. The supply from both is at present apparently unlimited, and there are only two drawbacks to the use of petroleum all over the world, for lighting and heating purposes, &c. The first is the cost and difficulty of transport, which will no doubt be overcome; the second is the varying composition and inflammable nature of the oil, necessitating great care in carrying and storing it.

**Scotch Oil.**—The third source from whence mineral oil is obtained is by distillation from bituminous shale or "petroleum peat." Dr. James Young was the first to discover, in 1850, that petroleum could be extracted from shale, rich beds of which exist in abundance in Scotland. The oil produced is usually known as paraffin oil.

Thus during the last forty years a vast and hitherto unsuspected store of natural fuel has been brought to light, which, unlike coal, requires no laborious mining process to extract it from the earth. It is merely necessary to bore a well of the requisite depth, with an instrument known as a well-driller, over which a wooden structure is erected, and the oil issues forth in a liquid stream. The boring is often now carried out by a motor driven by oil. Care must be taken, however, in the Caspian district, that the flow of oil is not allowed to become so great as to flood the country. Thus in the Droojba fountain, in 1883, the oil rose to a height of 300 feet, and flowed at the rate of 2,000,000 gallons a day. It burst to the surface with the force of a miniature volcano, carrying with it large quantities of sand, and the damage done to the surrounding country ruined the owners. About £10,000 worth of oil per day were thrown up, and most of it wasted. To check this tremendous flow, the wells are now "capped" at once if possible, and frequently covered over, or "corked," if the price of oil is at the time so low as to render the working unrenumerative. Thus the supply is stored for future use.

**Composition of Oil.**—The difficulties of utilising Nature's bount[illegible] stores of light and heat become apparent, as soon as [illegible] tuents of the oil are examined. The composi- [illegible] coal, wood, &c., varies considerably, and [illegible] uniform. Crude petroleum consists of [illegible] ering in their proportions in every oil,

and all are of different densities. The density of some is very low, and they are much lighter than water, taken as unity. The lighter the more dangerous the oil, because the more rapidly it evaporates, giving off inflammable vapours which ignite if a light be brought near. As the chemical constituents of petroleum have different boiling points, they are vaporised at different temperatures. Hence the difficulty of dealing with these oils. At a low temperature the lightest and most volatile hydrocarbons rise to the surface, and are first given off. As the temperature increases, and more heat is applied, the heavier and more inflammable vapours are separated, till at last all the volatile oil is evaporated, and a thick heavy liquid is left, called "astatki" in Russia, and "residuum" in America. Formerly this petroleum refuse was considered useless, and thrown away. Both in America and Russia it was allowed at times to run to waste, and formed lakes of liquid petroleum, which were often set on fire, to get rid of them, or carried off by pipes into the sea. It is now known that, though this refuse cannot be volatilised by the application of heat, however intense, it may be broken up or divided into spray and utilised, by injecting air or steam into it, and thus burning it. It is used extensively in Russia and America, and forms a valuable liquid fuel, though it does not yet pay for the cost of transport to other countries.

**Distillation.**—If American, Russian, or Scotch shale oil be heated gradually in a retort, it is divided up by what is called "fractional distillation" as follows:—The highly inflammable vapours, variously known as naphtha, gazolene, benzoline, petroleum essence, petroleum spirit, &c., are first given off. These vapours, though very dangerous, are free from impurity. As the temperature of the retort increases heavier gases are liberated, and carbon is deposited; while at a red heat the residuum is split up, or "cracked," and converted into a true oil gas, containing a large amount of tarry products. "Cracking" is the term applied to petroleum when, by subjecting it to great heat, the heavier chemical constituents, which will not themselves vaporise at that temperature, are split up and decomposed into lighter hydrocarbons, which are readily evaporated. The different oils thus formed are, in the order of their density, volatile essence or spirit; kerosene or illuminating oil; what is called intermediate oil, because in density and inflammability it is between the light and heavy oils; thick lubricating oil; and lastly, *astatki* or refuse, which may either be made into gas, or by the addition of superheated steam, burnt as fuel.

**Different Densities of Oil.**—It must not be supposed that these different classes of oil are ever rigidly defined in any petroleum. They pass one into the other, from lighter to heavier, by imperceptible gradations, and can only be correctly tabulated according to their density. Nor is even this an

infallible test of their quality, for the same oil, naphtha, kerosene, or lubricating oil, will often vary in density, according to the petroleum from which it is obtained. Sometimes an oil will contain more of the lighter, sometimes more of the heavier constituents. At Baku the lightest oils are found in wells of great depth, and hence the high pressure of the oil fountains, and the force with which they rise ; the heavier kinds lie nearer the surface. The difficulty caused by the varying density of petroleum, and the different temperatures at which it vaporises, is the main obstacle to its use in heat engines, and special means are employed in every case to convert it into spray. If the oil be simply injected into the cylinder like gas, the hydrocarbons are soon deposited, and are troublesome to get rid of. If only the lightest oils or spirit are used, they are even more easily ignited than gas, but they are expensive, and dangerous to transport. Legally they can only be used with special precautions in heat motors. The heavy liquid refuse is not inflammable, and therefore quite safe, but to employ it in an engine it must be previously distilled in a retort. It is the intermediate kinds of oil, obtained from heavy residuum after refining away the volatile essence, which are chiefly used for lighting and heating ; and petroleum, as distinguished from spirit or naphtha, motors, are usually driven by these oils only. If natural oils have been carefully refined, and their more volatile constituents drawn off by the application of heat, they become much less inflammable. Lighting oil or common kerosene will not ignite at the ordinary temperature, and will even extinguish a lighted taper when applied to it. Special legal restrictions are, however, placed on the use of oil in most European countries, and a test, known as the Flashing Point, is prescribed, to determine its inflammability.

**Flashing Point.**—The flashing point of an oil is the temperature at which it gives off inflammable vapours, and depends on its density or specific gravity—that is, the ratio of a given volume of its weight, as compared to the weight of the same volume of water, at the ordinary temperature of 60° F. Careful allowance must always be made for temperature in dealing with oil, because petroleum increases greatly in volume with every degree rise of heat. To determine its specific gravity, water [illegible] taken as unity, and the weights of oil as fractions. The high[illegible] the specific gravity of oil, or the more closely it approximates [illegible] the density of water, the less danger will there be of [illegible] mability. Petroleum which has a low specific [illegible] very light chemical constituents, and these [illegible] temperature. Hence it catches fire more [illegible] of greater density, containing heavier hydro[illegible]

The flashing point of oil is usually [illegible] an apparatus designed by Sir F. Abel. [illegible]

vessel of oil is immersed in another containing water. The tight fitting cover of the small oil vessel has three holes, which are opened by moving a slide. Through one a thermometer is passed into the vessel, and a gas burner and flame are fixed above the others. The oil is heated by raising the temperature of the water in the receiver by means of a lamp. At about 66° F., or 19° C., the slide in the cover of the air vessel is slowly withdrawn, the flame tilted till it is brought beneath the lid through the holes, and the oil watched until it lights or flashes. The flashing point is determined from the number of degrees rise in temperature of the oil. In most countries of Europe and America no oil may be used giving off inflammable vapours, that is having a flashing point below a certain limit of temperature, which is fixed by law. In England and Canada the limit is 73° F., or 22° C.; in America and Austria, 37·5° C.; in France, 35° C.; Russia, 28° C.; Germany, 21° C. The flashing point may also be roughly determined by holding a lighted taper above an open vessel filled with oil. As the temperature is raised by the heat of the taper, light hydrocarbons are liberated, rise to the surface and ignite, and if a thermometer be placed in the oil, the flashing point can be read off. The higher this limit of ignition, the safer the oil.

**Ignition Point.**—The ignition or burning point of oil is the temperature at which the oil itself, and not the inflammable

TABLE OF CONSTITUENTS OF PETROLEUM—SPECIFIC GRAVITY AND FLASHING POINT (*Robinson*).

| Constituents. | American Oil. | | Russian Oil. | | Scotch Shale Oil. | | Flashing Point. |
|---|---|---|---|---|---|---|---|
| | Volume | Specific Gravity. | Volume. | Specific Gravity. | Volume. | Specific Gravity. | |
| | Percent | | Percent | | Percent. | | Degrees C. |
| Benzine light oils, | 14 | 0·700 | 1·0 | 0·725 | 5·0 | 0·730 | −10 |
| Benzine heavy oils, | 2·0 | 0·730 | 3·0 | 0·775 | ... | ... | 0 |
| Kerosene lighting oils, . . | 50 | 0·810 | 27 | 0·822 | 35 | 0·805 | 25 to 5[illegible] |
| Intermediate, . | ... | ... | 12 | 0·858 | 2 | 0·850 | 105 |
| Lubricating pyronaphtha oils, | 15 | 0·880 | 32 | 0·903 | 18 | 0·885 | 110 to [illegible] |
| Paraffin wax (vaseline), . . | 2 | ... | 1 | 0·925 | 12 | ... | |
| Residuum and loss, | 16 | ... | 24 | ... | 28 | ... | |

vapours given off, takes fire. It is of course of gr
ance to determine the flashing than the burning poi
being reached long before the oil itself is raised t
point. As the lowest legal flashing point of an oil
73° F., naphtha or petroleum spirit, which ign

temperature and is very dangerous, may not be used. The flashing point of astatki or crude petroleum refuse is above 200° C.; intermediate Scotch shale oil has a flashing point of 105° C. = 221° F.

The table on p. 268 (from Professor Robinson's *Gas and Petroleum Engines*) gives the proportions, flashing point, and specific gravity of the different hydrocarbons contained in Russian, American, and Scotch petroleum.

The next table shows the chemical constituents of the oils from the different countries and their heating value :—

Chemical Composition and Heating Value of Different Oils (*Robinson*).

| Country. | Description of Oil. | Mean Specific Gravity. Water = 1. | Composition. | | | Mean Heat Value Per Lb. of Oil. B.T.U. |
|---|---|---|---|---|---|---|
| | | | C. | H. | O. | |
| | | | Per cent. | Per cent. | Per cent. | Heat Units. |
| Russia (Baku), | Heavy crude petroleum, | 0·938 | 86·6 | 12·3 | 1·1 | 11,000 |
| ,, | Light crude petroleum, | 0·884 | 86·3 | 13·6 | 0·1 | 11,480 |
| ,, | Astatki, | ... | 84·6 | 13·9 | 1·2 | 10,340 |
| America, . | Heavy crude petroleum, | 0·886 | 84·9 | 13·7 | 1·4 | 10,680 |
| ,, | Common petroleum, | ... | 88·3 | 13·9 | 0·8 | 10,102 |
| ,, | Astatki or residuum, | 0·928 | 87·1 | 11·7 | 1·2 | 10,680 |
| Scotland, . | Shale oil, | 0·860 | 86·5 | 7·0 | 0·5 | ... |

**Professor Robinson's Experiments.**—A series of careful and interesting experiments were undertaken by Professor Robinson, to determine the nature of the changes produced by heat in different kinds of oil. In order to ascertain the properties of oil, and how much additional heat was necessary to convert it into a vapour before using it in the cylinder of an engine, he desired to know the temperature at which the oil distilled or evaporated, and the pressure of the petroleum vapour given off. The first point could only be determined by the process of fractional distillation. A glass flask filled with petroleum was placed in a sand bath, and slowly heated by the flame of a Bunsen burner. Two thermometers were used, one in the oil, the other at the neck of the flask. By this apparatus Professor Robinson was able to take the temperature of the oil, and of the vapour as it was [illegible] off; the latter was then passed through a glass tube [illegible] with [illegible] water into a graduated condenser. With [illegible] boiling point would be always the same, but with oil [illegible] distillation ceased at one temperature, [illegible] The temperatures of the oil and [illegible] to agree completely, but [illegible] the

oil, the less difference there was between it and the temperature of the distilled vapour. A marked difference between the various oils tested was found, in the gradual or abrupt distillation of their constituents, and the percentage given off at the different temperatures. As a rule, Scotch shale oil distilled slowly at a high temperature, with the exception of Trinity or lighthouse oil, 55 per cent. of which distilled between 170° C. and 230° C. Some of the ordinary lubricating oils distilled rapidly at a temperature commencing at 120° C., the Russian at 130° C. The oils which distilled a large percentage of their volume within a limited range of temperature, showed a more or less uniform composition. Others evaporated slowly through a wide range, proving that they were more complex in composition, and made up of hydrocarbons having varying boiling points. Only a small percentage of the heavy, intermediate, and Scotch shale oils was distilled at a very high temperature. The range of temperature applied to these oils varied from 120° C. to 270° C. At a temperature of from 215° C. to 240° C., about 50 per cent. of the American and Russian oils distilled.

**Evaporation of Oil.**—The next experiments were undertaken to determine the evaporation from heavy oils in the open air, when exposed to a slow gentle heat, under ordinary atmospheric conditions, and thus the amount of light hydrocarbons they contained. Lighthouse, Scotch shale, and lubricating oils, having a specific gravity of 0·810 to 0·853, were tested. They were placed in shallow receivers, and a steady heat maintained beneath them, the temperature of the oils being kept for three hours at from 40° C. to 65° C. The amount of evaporation was determined by weighing the oils before and after the experiments, and it was found that the percentage of loss varied inversely as their specific gravity. With the heaviest lubricating oil, the loss in weight was 2·96 per cent., with the lightest oil of 0·810 specific gravity it was 6·90 per cent. in the same time. These experiments show the degrees of safety with which oils may be stored in hot climates, and the necessity of ventilating and keeping cool the oil tanks, thus diminishing risk and loss by evaporation.

**Pressures of Oil.**—Professor Robinson next endeavoured to determine the pressures of the different oils, corresponding with a given rise in temperature. Some difficulty was experienced in making these trials, because it was found much less easy to prevent leakage from the joints with petroleum vapour, than with steam or lighting gas. The testing apparatus consisted of a U-shaped glass tube, having one limb longer than the other. At the end of the shorter was a spherical bulb, the longer was provided with a graduated scale. The tube and bulb were filled with mercury and oil, the oil being uppermost in the bulb. The temperature was raised by placing the glass apparatus in a glycerine bath, gradually heated by a Bunsen burner. As

the sample of oil in the bulb increased in temperature, the pressure generated by its vapour forced the mercury down the bulb and up the longer limb of the tube, and its rise was noted on the scale. Corrections were carefully made for the temperature of the room, latent heat of evaporation in the oil, expansion of the glass and mercury, &c. The height of the mercury in the tube showed the pressure attained by the petroleum vapour in the bulb, corresponding to the rise in temperature of the glycerine bath. The results of the experiments were afterwards plotted on curves, showing the proportional increase of pressure with increase of temperature, in the same way as with steam. Professor Robinson gives various curves exhibiting the temperatures and pressures for different oils. It was found that steam had a higher pressure at a given temperature than any of the oils, except petroleum spirit or naphtha, the pressure of which rises more rapidly in proportion to its temperature. At 300° F. the pressure of petroleum spirit was 125 lbs. and that of steam is 55 lbs. per square inch. The pressure of ordinary oils was much less. Common lighting oils, chiefly American, gave an absolute pressure of a little above 150 centimetres of mercury, at temperatures varying from 170° C. to 200° C., while the heavy oils, as Lighthouse or Scotch shale, having a specific gravity of about 0·825, showed a very low absolute pressure,* 90 to 94 centimetres of mercury at a temperature of 200° C. The lighter the oil, the more nearly it approached the temperature and pressure of steam. At lower temperatures the oils exhibited great differences of pressure, but at the lowest temperature tested, about 80° C., all gave nearly the same pressure, viz., about 80 centimetres of mercury (absolute pressure). At temperatures below 100° C., the pressure of water vapour was very much higher than that of any oil.

The pressure of air at a given temperature being known, it is possible, with the help of these valuable tables, to determine approximately the temperature and pressure of petroleum vapour, and therefore the work which should be obtained from a mixture of oil and air in the cylinder of an engine. Much, however, remains to be done, and at present we know little about the action of petroleum under great heat in a motor. The difficulties of the subject are increased by the complex constitution of oil. The latent heat of evaporation of petroleum is about one-ninth that of water—that is, the same quantity of heat will evaporate nine times as much oil of average specific gravity as water, but the expansion of the vapour is only one-fifth that of water vapour or steam. Hence the same quantity of heat will produce $\frac{9}{5}$ or 1·8 times as much oil vapour as steam from

[illegible] e above data are from Professor Robin-

[illegible] low the pressure of the atmosphere.

son's able lectures at the Society of Arts on "The Uses of Petroleum in Prime Motors," to which the student is referred for an exhaustive treatment of the subject. Professor Robinson has been the first, as far as the author is aware, to make a special study of this difficult question.

**Utilisation of Oil.**—Having thus considered the chemical composition and properties of oil, it will be evident that though it can be utilised in many ways to produce heat, the process is complicated, because its constituents vary so widely. There are four methods by which petroleum may be used to generate mechanical energy in a heat motor.

I. As liquid fuel it is burnt under a boiler to evaporate water. In this case the petroleum is simply used as fuel, and produces the same effect. It is injected through a nozzle, with a proper admixture of steam and air, into the furnace, where it is burnt in the ordinary way. The heaviest petroleum and oil refuse may be thus employed to generate heat; the greater the specific gravity of the oil, the better suited it is for fuel.

II. Petroleum may be subjected to destructive distillation in a retort, and turned into a fixed gas, in the same way that lighting gas is distilled from coal. Any oil may be treated in this manner, but the best for distilling are the intermediate oils, which are neither so light that they escape before they can be gasified, nor so heavy that they cannot easily be broken up. The oil gas thus produced is exceedingly rich, having twice the heating value of coal gas. Mixed with air in proper proportions, this gas is introduced into the cylinder of an engine, and the force of the explosion drives the piston forward, as in a gas engine.

III. The lighter and more volatile constituents of petroleum, such as gazolene, benzine, petroleum spirit, essence or naphtha, are used, in the same way as oil gas, to work a motor. The spirit is previously prepared, and the heavier hydrocarbons withdrawn. Except that the power necessary to drive the engine is obtained by explosion, the action of the volatile spirit is similar to that of steam in a steam engine, the spirit being condensed, re-evaporated, and used continuously, as in the Yarrow spirit launch. The same spirit is also used as a fuel to vaporise the working agent.

IV. Ordinary petroleum is evaporated at a moderate temperature in an apparatus contiguous to the engine, and mixed with air is used, as in the spirit engine, to drive the piston by the force of explosion. Here also the oil constitutes both the fuel and the working agent. Engines employing this method to produce mechanical energy from petroleum may be divided roughly into two classes—(*a*) Those in which the whole of the crude petroleum is vaporised, and so broken up that practically no residuum is left; (*b*) Those working with oils of lower specific gravity, in which cold air is charged with the volatile hydrocarbons, and the heavy residuum wasted. Some of the latter may

almost be called spirit engines, as the oil they retain for use is very light and inflammable.

**Various Methods.**—All these methods of utilising petroleum as fuel present difficulties, owing to the complex nature of the oil, except when it is evaporated as a pure spirit. It was long thought impossible to burn the heavy astatki, but when converted into spray by injecting steam or air into it, it can under certain circumstances be profitably employed. When the petroleum is turned into a fixed gas difficulties arise, because the oil gas becomes laden with tarry products which, unless it is well washed and cooled, clog the pipes and valves. There is another obstacle when the lighter constituents of petroleum are utilised in an engine. These are given off at different temperatures, and the process is assisted if a large surface of the oil is brought in contact with the air. It is therefore agitated mechanically, the whole of the volatile constituents are gradually evaporated, and a heavy residuum remains, which is usually wasted. Some inventors prefer thus to utilise only the lighter and more inflammable portions of the oil, and to sacrifice the remainder, thereby obtaining much quicker evaporation, more power, and cleaner combustion than with heavier oils, though the consumption is greater. But the method more generally employed, as safer and less wasteful, is to evaporate the whole of the oil in the cylinder of an engine. This requires the application of external heat.

We will now consider—I. Petroleum as fuel, and II. Petroleum when converted into oil gas. In the next chapter we shall treat of III. The use of Petroleum spirit, and IV. Crude petroleum in oil engines.

I. **Petroleum as Fuel.**—The advantages of petroleum, when burned as liquid fuel, are so great that it is safe to predict it will in time compete with coal and other fuels, and become an important factor in the commerce of the world. There are now on the Caspian forty "oil steamers," in which the boilers are fired with astatki. All the locomotives on the Tsaritzin and Grazi Railway in south-east Russia are fitted with an apparatus for burning petroleum refuse, instead of coal, under their boilers. Coal in that part of Russia being dear and scarce, the economy thus realised is considerable. In fact the Baku oil fields have created the Caspian fleet. The uses to which petroleum is now being turned in Russia, where the oil is obtained on the spot, will probably be extended to other parts of Eastern Europe, as soon as the pipe lines have been laid along the Caucasus to the Black Sea.

**Difficulties.**—The difficulties attached to the use of petroleum [illegible]s complex constitution; secondly, its inflam[illegible]ly, its cost. The two first do not apply to [illegible]. The heavy oil used on the Russian

railways is scarcely more inflammable than coal, and there is consequently no danger in using it. This was proved during an accident on the line, when an engine and carriages left the rails, and the tank of astatki in the tender did not ignite. The constitution of the petroleum is also fairly uniform, because all the volatile hydrocarbons have been evaporated, and though it is heavy and difficult to break up into spray, yet when combined with injections of steam and air it forms a safe and excellent combustible. At present, however, it can only be used in countries producing it, on account of the cost of transport. In England it is not likely to compete with native coal, but it may in the future be found in our Colonies and Dependencies, and there be turned to great advantage for locomotive and marine engines. The steamships of the Chilian Company use 100,000 tons of petroleum yearly. An abundant supply is found in Peru, and oil fields are also being opened up in Ecuador. In Scotland we have an almost unlimited quantity of shale, capable of yielding 120 gallons of oil per ton, but it is chiefly utilised at present for making gas, and for metallurgical and other processes. The cost of petroleum delivered wholesale in London and Liverpool is—American Ordinary 3¾d. to 4d. per gallon; Russian Ordinary 3½d. to 4d. per gallon; Scotch Shale Oil 2¼d. per gallon.

**Advantages.**—The first advantage of using petroleum as fuel, whether under boilers or in the cylinder of an engine, is its purity. It contains no sulphur, and is said to give off little or no smoke. If the oil is perfectly consumed, petroleum is the cleanest of all fuel. Another gain is that additional oiling is seldom required in the cylinder of engines driven by petroleum, because it acts as a lubricant. Where the oil is used as liquid fuel to evaporate water, heat is economised because, as it passes automatically into the furnace from a tank, it is not necessary to open the fire door, and the temperature of the furnace is not lowered. Petroleum is also much more convenient to store, and occupies much less space than a corresponding quantity of coal. Lastly it is of much greater heating value, as shown by the amount of water it evaporates per lb. of fuel. It has twice the evaporative power of some coal. Professor Robinson quotes figures to show that it evaporates at least 50 per cent. more steam than best Durham steam coal. Russian petroleum refuse burnt in a series of shallow troughs under ordinary boilers evaporated 14½ lbs. of water per lb. of refuse; coal burnt in the same boiler gave an evaporation of 7 to 8 lbs. water per lb. of coal. So high a result is not obtained when the astatki is sprayed. Professor Unwin tested the evaporative value of petroleum under a steam boiler, and found it to be 12·16 lbs. water (from and at 212° F.) per lb. of oil burned. The rate of evaporation was 0·75 lb. water per square foot of heating surface. He estimates the calorific value of the

petroleum he used at about 25 per cent. higher than an equal weight of Welsh coal.

**Liquid Fuel.**—It is on the Russian South-Eastern Railway, between Grazi and Tsaritzin, that the value of petroleum as fuel for evaporating steam in locomotives has been thoroughly tested. Mr. Urquhart, the able superintendent of the line, has by degrees replaced coal by petroleum in almost all the engines under his charge. In the oil obtained at Baku there is a residuum of 70 to 75 per cent. after the volatile naphtha and ordinary kerosene have been drawn off by distillation, and prior to its utilisation under boilers on this railway enormous quantities of this refuse were thrown away. Before 1882 the locomotives were fired with anthracite, but after various attempts Mr. Urquhart succeeded in altering the shape of the fire box and tubes to burn petroleum. There are 423 miles of railway on the Grazi-Tsaritzin line, and 143 engines are now fired with petroleum. The specific gravity of the oil used varies from 0·889 to 0·911, and its weight is 55 to 56 lbs. per cubic foot.

The tank containing the petroleum is placed for safety inside the feed-water tank in the tender. The oil is drawn from the tank through a pipe, terminating in a nozzle, and injected into the furnace. The size of the orifice has been carefully determined by experiments. A smaller tube containing steam from the boiler passes down the centre of the oil pipe; the steam and oil mingle at the mouth of the nozzle, and are injected as fine spray into the fire box. At the junction of the tube and fire box they are open to the atmosphere, and the air, having free access, is drawn by suction to the nozzle, and enters with the steam and oil. The force of the mingled blast is sufficient to break up the oil into very fine spray, which is driven against a fire brick division in the lower part of the fire box, and thus still further subdivided, before it rises into the upper part of the furnace as flame. A bridge of fire brick is now used to divide the fire box into two sections, and round and through this each jet of air, steam, and petroleum vapour has to pass. The actual arrangements of the fire box, &c., vary of course with the class of boiler used, whether marine, horizontal, or vertical. Besides the locomotives, a great many stationary boilers are fired with petroleum. It was at first found difficult to keep the oil in a proper liquid state during the severe Russian winters. A certain quantity of solar oil (one of the lighter oils obtained from petroleum) is now added to it, and steam is carried from the locomotive boiler through the oil tank to heat it, by means of a coil of pipes.

**Cost of Working.**—As regards the cost of working with petroleum, the best proof of its economy is the fact that from 1882, when it was first used on this railway, to 1888, it gradually and entirely superseded coal. The saving in money is stated by Mr. Urquhart to be 43 per cent. In 1882 the consumption of coal

per engine mile, including wood for lighting up, was 55·65 lbs., costing 7·64d. In 1887 30·72 lbs. of petroleum refuse were used per engine mile, costing 4·43d. The expense of repairs was also much less, owing to the absence of sulphur in the oil. Other railways in Russia are now beginning to adopt petroleum as fuel. The locomotives on the new Trans-Caspian lines are fired with it, as no other combustible is available, and the stores of liquid fuel will probably form an important factor in the Russian advance across Central Asia.

On the question of the evaporative power and heating value of petroleum as compared with coal, Mr. Urquhart speaks with authority. He estimates the heating power of petroleum refuse at 19,832 B.T.U., and of an equal weight of good English coal at 14,112 B.T.U. Theoretically, 1 lb. of petroleum refuse evaporates 17·1 lbs. of water at a pressure of 8½ atmospheres, while 1 lb. of good English coal evaporates 12 lbs. water under the same conditions. In practice he found that the petroleum used on his engines evaporated, at this pressure, 14 lbs. water per lb., or 82 per cent. of the total possible evaporation.

**Petroleum on an English Railway.**—Some kinds of heavy petroleum are also utilised as fuel on the Great Eastern Railway. Mr. Holden, the locomotive superintendent, finding much difficulty in getting rid of the refuse from shale oil distilleries, tar from oil gas, green oil, creosote, and other heavy residuum, has adopted a method somewhat similar to the Russian plan, for burning them under boilers instead of coal. The oil used is entirely heavy refuse, thicker and less easy to evaporate than Russian astatki. It is conveyed from the tank through a pipe, and injected into a furnace, but the air passes to the spraying nozzle through a central pipe, and steam is twice sprayed on to the petroleum before it is sufficiently volatilised to be converted into fuel. In all cases where heavy oils are broken up by injection, superheated steam is found most effectual. The injector is in three annular concentric parts. The liquid petroleum enters one passage, a jet of superheated steam passes through another, carrying with it a current of air down the central tube. Before the oil reaches the nozzle, it is broken up into spray by the steam jet. After the petroleum, steam and air are sprayed into the fire box, a separate supply of superheated steam is injected into the petroleum, and completely atomises it. The vaporised liquid strikes against brickwork in the fire box, is broken up, and forms a broad, concentrated flame. On the bars of the grate a thin layer of fuel, usually cinders mixed with chalk, is kept burning, to maintain a uniformly high temperature, to decompose the oil, and ignite the spray. Arrangements are made to fire the boilers with oil or coal, according to the price at which they can be procured. It is sometimes cheaper to burn one, sometimes the other. As with the astatki burnt on the Russian

railways, the oil is so thoroughly mixed with steam and air that there is no smoke, unless it is purposely produced by diminishing combustion. The mixture employed by Mr. Holden consists of two parts coal tar, and one part green oil, and costs generally about 1¾d. per gallon. The same system of firing locomotives with oil refuse is used on the Great Western Railway in the Argentine Republic, where there are abundant oil fields.

**Bailey-Friedrich Engine.**—In this motor (which should be carefully distinguished from the Bailey hot air engine), the arrangement for burning the oil to evaporate the water is somewhat similar to that adopted in the locomotive engines driven by petroleum on the Russian railways. The double-acting vertical motor is a reproduction of the Friedrich steam engine with boiler and surface condenser, and can be fired either with coal or oil. When petroleum is used, it is drawn from a tank placed below the level of the boiler, injected into the fire box with a jet of steam to break it up into spray, and ignited as it reaches the grate. The flames heat the boiler tubes in the ordinary way. When starting the engine, before steam has been got up, the oil is injected with a stream of compressed air, obtained with a hand pump. The supply of steam to the jet of oil is regulated automatically through a diaphragm valve. Ordinary petroleum is used for this motor, and the consumption is said to be about 2·05 lbs. per I.H.P. per hour. The working cost depends of course upon the price of oil.

**Petroleum for Marine Purposes.**—Marine boilers have often been fired by petroleum. About 1867 experiments were made by Mr. Isherwood, of the United States Navy, on board the gunboat "Pallas," on liquid petroleum as fuel. He was convinced of its superiority to coal in heating value, convenience of storage, weight, bulk, absence of stoking, and consequent saving of manual labour. He found also that the lighter oils, which explode very easily, burn completely, and leave no deposit. Against these advantages must be set the great drawback of using petroleum to any great extent as marine fuel, namely, the danger of carrying an inflammable oil, giving off volatile gases at a low temperature, in bulk at sea. For this reason, no kinds of oil but heavy residuum and astatki are likely to be used at present for marine purposes, except on small ships. The oil tested by Isherwood was utilised in the same way as on the Russian and Great Eastern Railways—namely, injected into the furnaces, after being thoroughly mixed with steam and air. Petroleum refuse is as cheap in America as on the shores of the Caspian.

**Oil Gas.**—The manufacture of gas from oil differs little in ... from the process of distilling gas from coal. The oil is ... ured into a retort kept at a strong heat, and the ... is purified, washed, and cooled in the same way

as lighting gas. All oils are not equally fit for gas making. Very heavy oils, as tar or blast furnace oils, creosote, &c., though they are vaporised for a time by the application of heat, condense again under pressure, and cannot be converted into a fixed gas. The best way of utilising them is to burn them, as already described, under locomotive or other boilers. Oil of low specific gravity, as petroleum spirit, is too volatile and evaporates too readily. For making gas the best oils are the intermediate, such as Scotch shale oil, which are too heavy to be vaporised completely in an oil engine, but are found to yield a very rich gas, well adapted for the purpose of driving motors. Vegetable oils and animal grease, fat or dripping can also be used in this way. Such motors, however, worked with oil gas in the same way as a gas engine is driven with lighting or cheap gas, are not oil engines, properly so-called, and must be distinguished from them. They do not, as in true oil engines, prepare the fuel for combustion, as well as utilise it in ignition and explosion. They are in reality gas engines, the gas used being distilled from oil instead of from coal. Nor is the economy so great as in oil motors, because heat must be applied, first to turn the oil into gas, and then to convert the gas into energy. In oil engines one application of heat suffices for both purposes, but the power generated is not so great.

**Distillation of Oil Gas**—The method of distilling oil does not vary much in the different systems, though it is usually necessary to modify the process slightly, to suit the oil or other refuse utilised. Thus in Alsace and in parts of France where there are deposits of bituminous schist, the crude petroleum refuse is allowed to fall in a thin stream into the retort, which is kept at a dull red heat by means of a fire beneath, and after being purified the oil gas is stored ready for use. The gas obtained has twice the calorific value of the same volume of coal gas. In another process, where a wrought-iron retort is heated to a cherry red by a furnace, the gas distilled has four times the calorific value of coal gas, and costs about 60 centimes per cubic metre. The quality of the gas depends chiefly on the temperature of the retort. In other countries various substances are successfully distilled to produce oil gas, such as linseed oil in Brazil, castor oil in Burmah, palm oil in West Africa, mutton fat in Australia and South America, and in general fatty refuse of all kinds, wherever it is found in abundance. In Great Britain oil gas is usually made from Scotch shale oil, of specific gravity 0·84 to 0·87, flashing point from 235° F. to 250° F., and yielding about 100 cubic feet of gas per gallon. The heating value of this intermediate oil is much increased, if the oil be injected into the retort by means of steam jets. The steam is decomposed by the heat; CO, a gas very rich in lighting value, is formed by the combination of the oxygen in the steam and the carbon in the oil,

and deposit of solid carbon is prevented. The following table gives the chemical analysis and heating value of oil gas, as manufactured by Messrs. Rogers of Watford :—

TABLE OF COMPOSITION AND HEATING VALUE OF OIL GAS (*Robinson*).

| Constituents. | Volume of Constituent in 1 Cubic Foot of Oil Gas. | Heat Value per Cubic Foot of Constituent. Heat Units. | Heat Value of given amount of Constituent in a Cubic Foot of Oil Gas. Heat Units (lbs. × 1° C.) |
|---|---|---|---|
| Hydrogen, H, | 0·3161 | 191·13 | 60·40 |
| Marsh gas, $CH_4$, | 0·4617 | 584·36 | 269·80 |
| Luminiferous hydrocarbons, $C_2H_4$, | 0·1629 | 932·05 | 151·80 |
| Carbonic oxide, CO, | 0·0014 | 190·02 | 0·27 |
| Nitrogen, N, | 0·0506 | ... | ... |
| Oxygen, O, | 0·0073 | ... | ... |
| | 1·0000 | ... | 482·27 |

The first oil gas producer was introduced into England in 1815 by Mr. John Taylor, of Stratford, Essex. The oil was passed successively through two retorts, to vaporise it thoroughly. Experience has since shown that one retort, if kept steadily at a proper temperature, is sufficient to volatilise all the lighter hydrocarbons contained in the oil, and convert them into gas.

**Oil Gas Producers—Mansfield.**—The Mansfield oil gas apparatus is one of the oldest producers, and that most commonly used. Gas can be made in it, not only from petroleum, but from any kind of oil, fat, &c. Fig. 104 gives an external elevation of this producer. A is the receptacle containing the oil or fat, which becomes gradually heated and liquefied, if solid, by the heat from the retort below. From here the oil passes in a thin continuous stream into the siphon pipe S, where it is vaporised, and conducted through the wide tube or hood, B, to the retort, R, in which it is further decomposed, and made into a permanent gas. The retort is placed in the centre of a cast-iron casing, C, lined with fire brick, L. Before any oil is admitted the brick lining is heated, and the retort brought to a cherry red heat, or a temperature of 1,600° to 1,800° F., by the fire F under the retort. Unless combustion is carefully adjusted by means of the damper D at the top of the furnace, regulating the discharge of the products of combustion, and the open[illegible] H below, admitting the cold air, the quality of the gas [illegible]ugh which the oil passes into the [illegible]e retort, as seen through the sight [illegible]erry red. The gases from R pass [illegible] stand pipe P to the hydraulic

box H, where they are washed, and freed from the tarry products given off in the manufacture of gas, by forcing them through water. The hood B rests upon two sockets. O, above the retort, is filled with lead, which melts with the heat, the hood sinks into it, and an impervious joint is thus formed during the gas making process. The other socket, K, is filled with water to prevent the escape of gas unless there is any undue pressure, when it forces its way out. At V is another safety valve, in

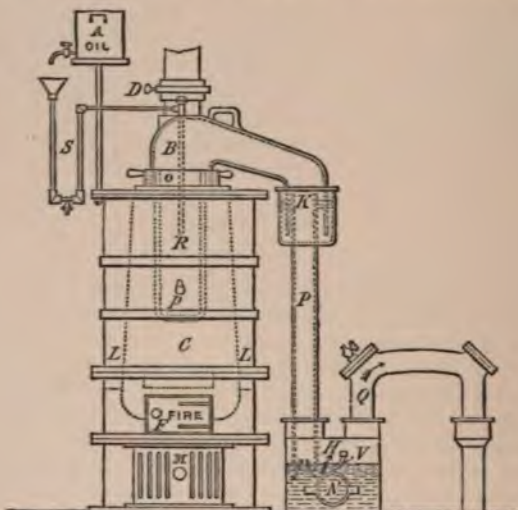


Fig. 104.—Mansfield Oil Gas Producer.

case too much gas is produced; the tarry deposits are withdrawn through the door N. The purified gases then pass through the pipe Q to a gasholder.

Two things are necessary to make good gas in the Mansfield producer. The heat of the retort must be sufficiently perfect to decompose the oil, and the stream of oil must be so regulated that no more passes in at a time than will produce a rich gas. With intermediate oil, 1000 cubic feet of gas are made from 7 to 9½ gallons of oil, or about 100 cubic feet per gallon. When used to drive an Otto gas engine, Messrs. Crossley give the consumption in a 12 H.P. motor at 9 cubic feet of gas per I.H.P., or 10 cubic feet per B.H.P. per hour, the gas being more than twice as rich as lighting gas. The total cost of oil and fuel, with oil at 4½d. per gallon, is about 6d. per 100 cubic feet. This is much more expensive than coal gas in England, but abroad, where coal is usually dearer, power may sometimes be most cheaply obtained by an engine driven with gas made from oil or

fat in a Mansfield producer. At the Melbourne Exhibition in 1888, an Otto engine was driven by gas thus generated from dripping or fat at the rate of 100 to 120 cubic feet per gallon. The flashing point of the fat was above 400° F., and it was previously liquefied by a burner.

**Keith.**—The Keith oil gas producer is especially adapted for oil made from Scotch shale. The principle on which the gas is made is the same as in the Mansfield producer, but the process is more rapid. The oil filters down through shallow iron troughs placed in the retort, till it reaches the lowest part, where the temperature is highest. Here it is converted into a gas and led off to the washer, and then direct to the gasholder, where it is cooled and stored. The pipes are large, and the pressure of the gas is kept low until it has passed to the holder. As it is principally intended to drive engines, it is unnecessary to purify it further. For illuminating purposes it is again passed through lime and sawdust, and after it has reached the holder, the pressure is raised by compression pumps to 150 lbs. per square inch. The gas produced, of 60 candle power, is exceedingly rich, and too powerful to use in a gas engine without altering the valves and passages. It is therefore diluted with air in an apparatus called a mixer, in the proportion of 35 parts by volume of air to 65 parts of oil gas, and is then of about the same strength as the lighting gas used in motors. It is, of course, again diluted with the proper proportion of air, when introduced into the cylinder of an engine.

The most important application of the Keith oil gas process is on the Ailsa Crag lighthouse in Scotland. Here it supplies five 8 H.P. Otto gas engines, working the air compressors for the two fog signals. There are four air-pump cylinders, each 10 inches diameter and 18-inch stroke; they are driven at a speed of 160 revolutions, and the air is compressed to 75 lbs. per square inch. The fog signals are in different parts of the island, at a considerable distance from the air compressing station. To supply power for fog signals, which are often required at a few minutes' notice, gas engines are of special value, because they can be started without delay. In this lighthouse twelve gas retorts are used, producing 10,000 cubic feet in four hours from 100 gallons of ordinary illuminating paraffin, distilled from Scotch shale. From 20 to 30 cwt. of coal are required to heat the retorts. The four engines consume 26 cubic feet of pure oil gas per H.P. per hour, or 6·5 cubic feet for each engine. The price of the gas is 5s. 9d. per 1,000 cubic feet; total cost of working, about 1·16d. per effective H.P. per hour. The output is rather expensive, owing to the isolated position of the lighthouse, and cost of carriage of coal and oil.

**Rogers.**—In the oil gas made by Messrs. Rogers, of Watford, steam heated by the waste heat from the furnace is injected with

the oil into the retorts. The steam is decomposed, and the oxygen contained in it combines with the carbon of the oil to form carbonic oxide, thus preventing the deposition of solid carbon to any considerable extent. Another producer has been designed by Mr. Thwaite, to utilise poorer oils than can be burnt in the cylinder of an oil engine. The system is somewhat similar to those already described, but the retort is placed in the centre of a slow combustion coke furnace. The oil trickles down the middle of the retort, and becomes completely gasified as it passes up the annular space at the side, which is heated by contact with the coke furnace. In all these processes, where the oil is first turned into gas, and then used to drive a motor, more power is developed than where it is evaporated directly in the cylinder, although some heat is lost.

**Pintsch.**—The Pintsch oil gas system differs from those already described because the oil, being intended principally for illumination, is more thoroughly purified. It is introduced successively into two retorts, one above the other. The upper, into which the oil first enters through an inverted siphon, is kept at a moderate temperature; the lower retort, in which the process of evaporation is completed, is at a cherry red heat. As it enters, the oil is received on sheet-iron trays, over which it passes to the upper retort, and descends through pipes to the lower. It has now become a thick yellow vapour, in which shape it enters a hydraulic box, where it is partially washed, and thence passes to the condenser, the tar being carried off by overflow pipes to a separate tank. The gas is finally purified by forcing it through a vessel, the lower part of which is filled with water, and the upper with lime and sawdust. When cooled, it can be stored in the condenser at a pressure of about 10 atmospheres. The illuminating power of the gas produced is about 40 or 50 candles, but the pressure causes it to lose 20 per cent. of its lighting power. The best and cheapest oil for the purpose is Scotch intermediate oil, having a specific gravity of about 0·840, and yielding between 80 and 90 cubic feet of gas per gallon of oil. The price of the gas varies according to the cost of the oil, fuel, &c., from 5s. 6d. to 16s. per 1000 cubic feet. The carriages on the London Metropolitan and other railways have been for some years lighted with compressed Pintsch oil gas, at a cost of about 6s. to 7s. per 1000 cubic feet. It is also much used for lighting buoys at sea and in rivers, and is burnt in the floating lights on the Suez canal.

# CHAPTER II.

## HISTORICAL—WORKING METHOD IN OIL ENGINES—CARBURETTED AIR.

CONTENTS.—Oil Motors—Carburators—Lothammer, Meyer, Schrab—Vaporisation of Oil—Oil Engines—Hock—Brayton—Spiel—Siemens.

**Oil Motors.**—Having examined the first and second methods of applying oil to produce motive power, and considered it I. as liquid fuel, and II. as a gas, we now come to the study of oil motors, properly so called. Even gas engines, though far more handy than steam, are not suitable for every purpose for which motive force is required. For small powers, where steam cannot be used, because of the complication of a boiler, nor gas, when there are no gasworks near, petroleum engines supply a want, and have undoubtedly a great future before them. It is a peculiarity of these motors that the fuel is delivered to them direct, so to speak, in its original condition. In a steam engine the water must first be evaporated over a furnace; in a gas motor the working agent must either be distilled in a retort, or produced in a generator. The fuel for a petroleum engine may be purchased anywhere. No previous conversion into vapour is needed before it is delivered to the engine, and thus the cost of an additional gasifying or evaporating apparatus is saved. An oil engine is self-contained, and independent of any external adjunct, but to turn this advantage to account the difficulties of the constructor are somewhat increased. Not only must the engine be designed to utilise the working agent, and obtain mechanical energy from it, but the working agent must itself be produced, and the fuel prepared for combustion. This rather complicates the working of the motor, since it must vaporise the oil, keep the quality of the spray produced uniform, and make it a proper medium for the heat imparted to it.

There are two methods, Classes III. and IV. of the divisions in the pr[illegible] chapter, by which oil may, in the cylinder of an engine, be [illegible] into a source of energy, viz. :—

III. [illegible] naphtha, benzoline, or carburetted air is [illegible] the piston of an engine by the expansion [illegible]

IV. Ordi[illegible]rmediate oil is also used to drive an engine by [illegible]pansion, after its evaporation and conversion into [illegible] Class III. atmospheric air at ordinary tem[illegible] is charged with volatile

spirit, in Class IV. the petroleum is pulverised and broken up into spray by a current of air, with the addition of heat.

It must not be supposed, however, that all oil engines can be rigidly classed under either of these two divisions, because of the complex nature of petroleum, and the different temperatures at which it evaporates. In one engine, the Yarrow spirit launch, nothing is used, with due precautions, but pure and rather dangerous petroleum spirit or ether. In a few motors, as the Priestman and Trusty, the oil is so thoroughly pulverised and converted into spray (like the liquid fuel on the Russian railways) that the whole is evaporated and no residuum left. There are also a large number of oil engines, evaporating more or less of the volatile constituents of the petroleum, and with a proportionally large or small refuse, according to the amount of heat applied during the process, and the specific gravity of the oil used.

There are two methods of evaporating petroleum, both used to prepare it for driving an engine—viz., hot and cold distillation. We have seen that, the less the specific gravity of the oil, the more volatile it is. The higher the temperature to which it is exposed, the greater the evaporation, or the amount of hydrocarbons given off. It is only the light and highly inflammable spirit used in engines of Class III. which can be evaporated from petroleum without the application of heat. The heavier oils, of greater specific gravity, must always be heated, not only to vaporise the larger portion of their constituents, but to counteract the cold produced by evaporation.

III. Distillation at ordinary atmospheric temperatures is produced in the following way:—Atmospheric air is passed over light hydrocarbon oil (refined petroleum), and a volatile spirit is given off in large quantities, impregnating the air in contact with it. This carburetted air is equal in lighting and heating properties to coal gas, and, mixed with a proper proportion of ordinary air, it is sufficiently inflammable to ignite, and to do work in the cylinder of an engine by the force of the explosion. Sometimes, instead of passing the air over a layer of the oil, a current is driven through substances impregnated with the volatile spirit. The specific gravity of this petroleum spirit varies from 0·650 to 0·700, and its flashing point is generally so low that it cannot be used for commercial purposes. Motors in which it is employed ought scarcely to be called "oil engines." The working agent is simply inflammable petroleum essence, and is perhaps best distinguished by the term usually applied to it abroad—"carburetted air." The ease with which this spirit can be obtained from ordinary petroleum by merely passing air over it shows that care is necessary. An inflammable vapour generated without the application of heat, will ignite at ordinary temperatures, and ot safely be stored. Nearly all the early petroleum motors

employed this spirit as the motive power, and this is perhaps one reason why they did not come into general use. Owing to the inflammable nature of the working agent, a prejudice existed against them, which extended to all oil motors, and was not removed until the Priestman engine showed how ordinary oils could be utilised in the cylinder of a motor without danger.

Engines driven with carburetted air are also open to two objections from an economic point of view. The continued evaporation of the more volatile portions of the petroleum leaves a heavy useless residuum, difficult to get rid of. As the spirit is given off, the cold produced by evaporation rapidly reduces the temperature of the oil, and renders it less ready to part with the lighter constituents. These essences also carry off with them mineral or organic substances, which when burnt in the cylinder leave a thick deposit, and clog the working parts. Explosive gases therefore, produced by passing cold air over petroleum oil, are not suitable for use in a gas engine.

These difficulties are partly remedied by another method of obtaining carburetted air for a motor. The oil cistern or tank is placed near the cylinder, its temperature is thus raised, and the oil is agitated, in order to bring a larger surface in contact with the air. If the oil is slightly heated, not only will evaporation proceed more quickly, but less dangerous oil, having a greater specific gravity, can be used. The cost of working is also less, because volatile oils, having a specific gravity of about 0·650, are costly as well as dangerous. There is another advantage in placing the oil tank and carburating apparatus near the engine. Air which can be rapidly carburetted by bringing it in contact with petroleum essence, becomes decarburetted with equal facility, if exposed to a low temperature or pressure, or conveyed to the cylinder in long pipes. To carburate it therefore close to the engine economises the heat, and produces a more permanently inflammable gas.

**Carburators.**—There are many devices for producing carburetted air by passing it over petroleum spirit, but with most of them the gas obtained is only used for lighting. In America it is frequently made in the cellars of a house, as it is wanted for domestic purposes. The petroleum spirit or gasoline is stored in underground tanks, and air at ordinary temperature is pumped on to it through a pipe, and then drawn off and conveyed to the house burners. On this small scale there is little danger in employing carburetted air, but carburators above ground cannot be used with perfect safety. In most of them the principle [illegible] same. Air is forced either by compression or [illegible] over petroleum spirit, and becomes im[illegible]nce. In the *Lothammer* carburator air [illegible] is pumped into an outer reservoir, [illegible]r partly filled with the carburating

liquid. It next passes at high pressure from the outer reservoir into tubes, which are carried down into the inner receiver below the level of the liquid. Here it is discharged through radiating horizontal pipes, and forced to pass upwards, the pressure of the air breaking up the liquid. By this process the air becomes thoroughly saturated with the volatile essence, and is then drawn off and stored. M. Lothammer claims to obtain a gas which does not lose its heating qualities, even when exposed to a temperature of – 18° C. on leaving the carburator. Drawings and a description of the Lothammer apparatus will be found in Chauveau.

In the *Meyer* carburator heat is employed to charge the air with petroleum essence. The oil or hydrocarbon liquid falls drop by drop into a small boiler, where it is evaporated by the heat from a burner below. The oil vapour at a high pressure next passes through an injector, where a proper proportion of air is drawn in with it, and the two are thoroughly mixed before they enter the gas holder. Production is automatic, and the bell of the gasholder is made to regulate the admission of oil to the boiler, and the size of the flame. This method is said to produce carburetted air of nearly 10,000 calories per cubic metre heating value; it is principally used for driving engines. An ingenious method of carburating air, which does not yet seem to have been applied in practice, has been proposed by M. Schrab. Hydrocarbon liquid is substituted for water in the jacket of an engine cylinder, and is heated to about 80° C. by radiation from the walls. It then passes into a vaporising chamber, through which the exhaust gases are driven. The gases compressed into the boiling liquid become charged with hydrogen, carbonic oxide, and other combustible vapours, and return to the cylinder, where they form the fresh charge, and are ignited and expanded as before. The inventor affirms that these gases only require one-sixteenth as much petroleum essence to form an explosive mixture, as would be needed if fresh air were used, and that 1 litre of gazolene per H.P. is sufficient to work his engine for 10 hours. The idea has not apparently been further developed. There are numerous other carburators, especially in France, as the Mounier, Pieplu, &c., but they are chiefly used to furnish carburetted air for illumination. Each oil motor employs a special type of carburator, or method of vaporising the oil, and these will be described later, in the account of the various engines.

**Utilisation of Oil.**—Professor Unwin is of opinion that the three methods of utilising petroleum, as fuel under a boiler, as oil gas, and to carburate air, are none of them capable of any wide application, owing to the expense, the difficulties of transport, and the danger of using a highly inflammable liquid. The true oil engine of the future is probably of the fourth class, and comprises motors using and more or less completely eva-

porating ordinary lighting or heavy petroleum oils. Oil engines, however, are still in their infancy. If gas engines are younger and more modern than steam, and therefore have more possibilities of future development, the same applies in a still greater degree to oil engines. In some respects a greater heat efficiency, both in theory and practice, ought to be obtained from oil than from gas motors. In the latter the gas must be kept cool till it is introduced into the cylinder, and therefore, as it has hitherto been found impossible to utilise the exhaust gases, a large proportion of the heat is wasted. In an oil engine the working agent should be at a high temperature from the first. A certain amount of heat is necessary to render the oil fit for evaporation, and this heat is usually supplied by making the exhaust gases circulate round the oil tank or vaporiser. Hence more heat is utilised, the exhaust gases are comparatively cool at discharge, and a better working cycle should be the result. Hitherto, however, in the few trials made on oil engines, the heat efficiency is found to be about the same as with gas engines.

IV. In the fourth method of producing heat from oil—namely, by evaporating ordinary petroleum, and firing it as in a gas engine—the density of the oil used varies from 0·800 to 0·840. To ignite so heavy a liquid, and utilise the force of the explosion to drive a piston, the oil must be broken up into spray, and converted at a high temperature into an inflammable vapour, before it is admitted to the cylinder. A blast of compressed air is generally forced into the petroleum, to divide it up; the process is sometimes assisted by the injection of steam. All oil engines have a vaporiser or hot chamber, where the petroleum, either liquid or in the form of spray, is converted into vapour. The vaporiser is usually heated by a lamp at starting only, and afterwards by the exhaust gases. The air necessary for combustion is admitted and mixed with the charge of petroleum, after the latter has become vapour by the application of heat, air, and steam. The mixture is then drawn into the cylinder, as in a gas engine, by the suction of the piston. The process of ignition is rather delicate, because of the inflammable nature of the oil. Sometimes a hot tube is used, but in general electric ignition is preferred. A gas engine [illegible] ing the latter method can easily be driven with petrol[illegible] merely adding a carburator. A safety or non-return [illegible] also necessary, to prevent the flame from shooting back [illegible] vaporiser. With these precautions ordinary lighting [illegible] a flashing point of from 25° C. to 50° C. may [illegible] mechanical power, as safely as gas or [illegible] been adapted to any extent for marine [illegible] small power launch engines, because [illegible] storing quantities of inflammable liquid [illegible] ship carrying light petroleum spirit, it would [illegible]

get rid of the fuel. The spirit being lighter than water, if sent overboard, would float on the surface of the water as a sheet of flame. The danger would be much less if heavy petroleum were used.

**Vaporisation of Oil.**—There are three ways in which oil is treated, when employed as a combustible in the cylinder of an engine. In the first, it is broken up into spray, and thoroughly mixed with air, before it passes into the cylinder, as in the Priestman engine. In the second, liquid oil is injected into compressed and heated air, and instantly vaporised, as in the Hornsby-Akroyd engine. The third method is to admit the oil in small quantities into a vaporiser maintained at a very high temperature, which acts as a retort, and converts the oil into gas before it reaches the cylinder, as in the Trusty and Capitaine engines. One or other of these principles is followed in almost all oil motors, to render the petroleum fit for combustion, but a different arrangement is adopted in each particular engine, for the admission and vaporisation of the working agent or fuel.

**Oil Engines.**—The earliest attempts to use petroleum to produce mechanical energy were made soon after the introduction of gas engines. At that time, however, it was considered impossible to use ordinary petroleum, of about 0·800 specific gravity, because the difficulty of evaporating it was so great. To break it up into spray by a blast of air had not been proposed. Light petroleum spirit or inflammable ether was therefore employed, and probably retarded the development of the oil engine.

**Hock.**—About twenty years ago two engines appeared almost simultaneously, the Hock in Vienna, and the Brayton in America. In the Hock engine, the patent for which was taken out in 1873, benzoline or volatile hydrocarbon gas was used, drawn from a reservoir at the back of the horizontal cylinder. The engine was of the two-cycle, single-acting, non-compressing type, with an explosion every revolution; the whole series of operations was carried out in one forward and return stroke. On one side of the cylinder was a small valve chest containing two valves, one for the admission of air, the other for the discharge of the exhaust gases, both worked by an eccentric from the main shaft. On the other side was the igniting apparatus. A little air pump, driven from the crank shaft, forced a current of air at each stroke into a small receiver filled with benzoline. The air became charged with benzoline, and a stream was directed through a nozzle against a permanent burner, placed close to an opening at the back of the cylinder. The benzoline ignited at the flame, a flap covering the admission valve was lifted by the suction of the in stroke, the flame drawn in, and the mixture in the cylinder ignited. The permanent burner was fed with petroleum spirit from the same receiver.

The motor piston having passed the inner dead point, the suction of the out stroke drew a small quantity of hydrocarbon, at atmospheric pressure, from the reservoir at the back through a nozzle into the cylinder. At the same time a flap valve was lifted, and a stream of air, also at atmospheric pressure, was admitted through another nozzle beside it. The two nozzles being set slightly inclined to each other, the air pulverised the benzoline, and broke it up into spray. As the charge was too rich to use, it was next diluted with a second supply of air from the valve chest. When the piston had passed through about half the stroke, ignition took place as already described, the mixture being so arranged, that the richest portion lay nearest the ignition flame. The return stroke discharged the products of combustion. The centrifugal governor driven from the crank shaft acted by regulating the supply of air from the valve chest. If the speed was increased, the valve was held open longer, a larger quantity of air was admitted, and less benzoline. When the speed was reduced, and the balls of the governor fell, less air entered, the composition of the charge became richer, and the explosions more certain and stronger. This engine was popular for a time, but it was not permanently successful, on account of the inflammable nature of the petroleum spirit used. Drawings are given in Schöttler's book.

**Brayton.**—The engine patented by Brayton in 1872, and first constructed at Exeter, United States, was introduced into England about 1876. It was a better and more practical motor than the Hock, because the oil used was of greater density, higher flashing point, and less inflammable. Brayton was the first to employ ordinary heavy petroleum and kerosene, boiling at about 150° C., in the cylinder of an engine, instead of light spirit or essence. His engine, called the "Ready Motor," was also the first, and till now the only engine of any note, to embody the principle of combustion at constant pressure, instead of at constant volume. It was originally worked with gas, and was first brought out in America; the English patent was acquired by Messrs. Simon of Nottingham, who introduced it into this country in 1878 (see p. 51). A view of the Brayton-Simon engine is given at Fig. 11. The charge of gas and air was ignited before its admission into the cylinder, entered in a state of flame, and drove the piston forward without any rise in pressure, a steady combustion being maintained behind it durir [illegible] one-third of the forward stroke. As Brayton found [illegible] the [illegible] ne of the gas, in spite of the gauze [illegible]ragm shutti[illegible] off [illegible] the pump cylinder, was apt to [illegible] back, and [illegible] the [illegible]essed charge in it, he substi- [illegible] f gas, as the motive power. [illegible]s 0·850, and one volume of [illegible] volumes of air.

[illegible] the Brayton engine over

the Hock was that both the air and the oil were admitted, at high pressure, into the motor cylinder from two pumps worked from the main and the auxiliary shafts. The pressure of the injection pulverised the petroleum, and the air became thoroughly impregnated. In all oil engines hitherto constructed, the use of light petroleum spirit made it unnecessary to spray the oil. The system of breaking it up by forcing a blast of air into it rendered possible the use of heavy petroleum oil. Brayton was therefore the inventor of the first safe and practical oil engine, and in this respect his motor was the forerunner of the Priestman. Various modifications of it were brought out, some horizontal, others vertical, and one double-acting type is mentioned by Professor Witz.

As shown at the Paris Exhibition of 1878, the Brayton engine was vertical and single acting, resembling the Simon at Fig. 11, p. 52, except that the crank and distributing shaft are above the cylinder. There is an impulse every revolution. The two pistons, motor and compressor, work downwards upon a beam joined to the motor crank by a connecting-rod. Both cylinders are of the same diameter, but the stroke of the compression pump is half that of the motor piston. From the pump, part of the compressed air is delivered direct through the carburator into the motor cylinder, and part is forced into a reservoir in the base. The air here stored is intended to equalise the pressure, and to assist in starting the engine. On the other side of the motor cylinder is a small pump worked from an eccentric on the auxiliary shaft, to inject petroleum into the carburator. The different lift-valves to motor cylinder, pump and exhaust, are worked by cams from this auxiliary shaft, driven by bevel gear from the crank shaft, and revolving at the same speed. The admission cam to the working cylinder is moveable, and is shifted by the governor, in order to admit more or less of the charge, according to the speed of the engine.

**Carburator.**—Fig. 105 gives a view of the carburator placed at the top, just above the motor cylinder. It is in three compartments. The carburation of the air takes place in the middle division R, which is filled with felt, sponge, or other porous substance, and is separated by a layer of perforated metal plate at P from the space below, C, communicating through the opening D with the motor cylinder. The chamber C is always full of flame. Petroleum is injected from the small oil pump through pipe E, and air from the pump through F into R. The jet of air pulverises the petroleum and breaks it up into spray, which thoroughly impregnates the porous m
At this moment the valve V rises,
the pipe O into the outer cham
through R, it carries with it a port
and is ignited on reaching C. F

the cylinder in a sheet of flame. There is no explosion, the pressure of combustion of the charge being sufficient to drive out the piston. Thus, as in later oil engines, air is twice applied, first to break up the petroleum and convert it into spray, and then to dilute it in the same way as the charge in a gas engine. When the piston has passed through one-third of its stroke, the valve V closes, shutting off communication with the outer air, and the ignited vapour is expanded through the remaining two-thirds of the stroke. During the return the products of combustion are discharged. As the diagrams show, the pressure in the Brayton engine is not high, and expansion is prolonged. Meanwhile the two pumps have injected a fresh charge of compressed air and petroleum into B, and by the time the piston has completed the in stroke, and before the valve V rises, the porous material filling the chamber is saturated with pulverised petroleum, ready to be carried into the cylinder at the next admission of air. To start the engine, petroleum is pumped in by hand, and compressed air admitted from the reservoir, and when the carburator is full of oil vapour, the little plug at G is withdrawn, and a lighted match applied; the mixture ignites, and the piston begins to work.

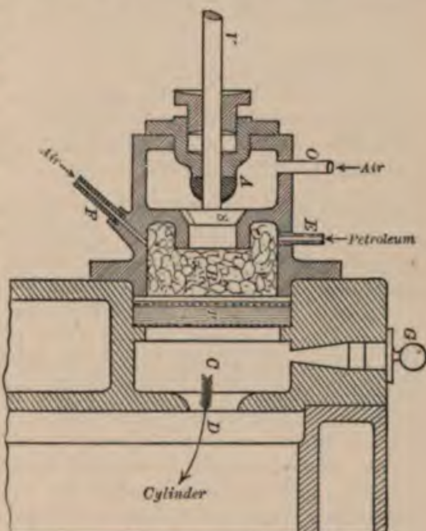


Fig. 105.—Brayton Carburator.

The Brayton engine is constructed on the same principle as the Davy safety lamp, namely, that of preventing back ignition by the use of a wire gauze, or perforated metal plates. It was found that, when heavy petroleum was used, the flame did not shoot back, though with compressed gas, accidents were of frequent occurrence. Combustion in the chamber C is maintained constant by the compressed air injected at F, and the engine is said to work with extreme regularity. The change introduced by
nary petroleum is, under certain
as lighting gas, but as used by
ge. The petroleum vapour
he passages, ports, &c., and

the engine required frequent cleaning. Some of the deposit helped, it was said, to lubricate the engine.

**Trials.**—A careful trial of a 5 H.P. American Brayton petroleum engine was made at Glasgow by Mr. Dugald Clerk in 1878. The mean pressure was 30·2 lbs. per square inch, diameter of cylinder 8 inches, length of stroke 12 inches. The engine made 201 revolutions per minute, and the consumption of petroleum was 2·16 lbs. per I.H.P. per hour. Much of the total power developed was absorbed in driving the air and petroleum pumps, or in other words there was a good deal of friction. During the trial the engine indicated 9·5 H.P. in the motor cylinder. Of this the pump absorbed 4·1 H.P., therefore the available H.P. was only 5·4. Only 6 per cent. of the total heat generated was utilised. The results show a much lower efficiency than might have been expected, owing to faulty construction. Fig. 106 gives a diagram taken from the motor cylinder during the trial, in which the prolonged expansion obtained with ignition at constant pressure is noticeable.

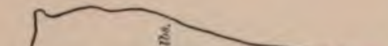

Fig. 106.—Brayton's Petroleum Engine —Indicator Diagram.

**Spiel.**—Both the two motors described above were brought out before the success of the Otto engine had fully established the superiority of the four-cycle type. In the next oil engine, patented by Spiel, and made in England by Messrs. Shirlaw & Co., Birmingham, the Beau de Rochas four-cycle is introduced, and the engine resembles the Otto in many respects. It has the drawback of using inflammable petroleum spirit of 0·700 or 0·730 specific gravity, instead of the safer heavy petroleum. Being easily volatilised, this spirit does not require so complicated a process to convert it into spray as in engines employing oil of greater density, and the method of introducing it in the Spiel is simple. The engine is horizontal and single-acting, standing on a solid base, with the reservoir of oil above. The organs of admission, distribution, and exhaust are worked from an auxiliary shaft, geared from the main shaft in the usual way. The exhaust is opened, as in the Otto, by a cam and levers from this shaft, and ignition is by a flame carried in a slide valve, working at the back of the cylinder; the Spiel is probably the only oil engine firing the charge in this way. A portion of the compressed charge of oil and air in the cylinder passes through a grooved passage to a chamber in the slide valve which, as the slide is moved by a cam on the auxiliary shaft, is brought opposite a permanent flame in the valve cover, and fired. A spring effects the return movement of the slide valve, when released by the cam, and the lighted mixture is brought in line with the cylinder port, when the remainder of the charge is fired. The pressures

of the charge in the cylinder, and of the flame in the ignition port are equalised, as in the Otto engine, by means of a small passage connecting them.

The benzoline is drawn from the reservoir and injected into the cylinder by a small pump, the piston of which is worked by a cam, lever, and spring from the auxiliary shaft. The air-admission valve is also in connection with a crosshead attached to this pump. At the bottom of the pump is a double-seated horizontal lift valve, usually held open by a spring, in which position it communicates freely with the oil reservoir above. When the plunger pump is driven down, carrying with it the crosshead, the air valve is first lifted, and air enters a mixing chamber at the back of the cylinder. As the piston continues to descend, the horizontal valve is closed, and a passage opened from the pump into the mixing chamber. The pump sends a jet of petroleum spirit into the air, and in its passage it is broken into spray by striking against a projection. Thus the out (admission) stroke of the motor piston sucks into the cylinder a stream of air mixed with petroleum spray. The engine has a ball governor which, if the speed be too great, interposes a small projection between the valve-rod of the pump and the levers working it. The two become locked and cannot move, and the valve remains open, admitting air only to the cylinder, until the projection falls back, and the speed is reduced.

Drawings of this engine are given by Robinson and Schöttler. Fig. 107 shows an indicator diagram of a Spiel oil engine when making 180 revolutions a minute. The consumption of oil, when this diagram was taken, was about 1 pint per B.H.P. per hour. In another 14 B.H.P. Spiel engine having a cylinder diameter of 9½ inches, with 18 inches stroke, and making 160 revolutions per minute, the consumption of naphtha was 0·81 lb. per B.H.P. per hour, and the cost of working 0·84d. per B.H.P. per hour.

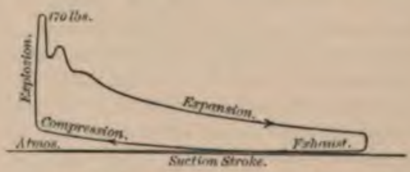


Fig. 107.—Spiel Engine—Indicator Diagram.

The specific gravity of the oil used was about 0·725. It is contended by the English makers of the Spiel engine that, in spite of the difficulties of storing and transporting naphtha, owing to its inflammable nature, it is greatly superior to heavy oils for producing motive power. Some interesting experiments were ... lel engine, running at over 500 revolutions ... Beau de Rochas cycle, comprising the ... compression, explosion plus expansion, ... it four times in a second. In another

experiment it was found possible, with an initial pressure of over 300 lbs. per square inch, to remove the ignition flame, and obtain regular spontaneous combustion of the charge. Some hundreds of these engines are said to be at work.

**Siemens.**—No account of internal combustion engines would be complete, without a mention of the motors designed and patented by Sir William Siemens. In 1860 he first devoted his attention to the subject, and from that time till 1881 he brought forward various engines, all intended to illustrate the principle of utilising the waste heat of the exhaust gases, by passing them through a regenerator before discharge. The incoming mixture entered the cylinder through the same regenerator. This idea of a regenerator in heat motors originated with Dr. Robert Stirling, a Scotch minister, in 1827, but it has hitherto been found impossible to apply it in practice, except in the case of hot air engines, though in metallurgy and other manufactures it is largely used.

Sir William Siemens made many alterations and improvements in the heat engines he designed. In one he proposed to add a gas generator, producing water gas by the passage of steam and hot air under pressure through incandescent fuel. The gas thus made was pumped into a reservoir, and from thence into four cylinders, each serving to charge the next through a regenerator formed of layers of metallic gauze. As the gas entered each cylinder it was ignited, and the burning gases expanded at constant pressure. This engine was not worked; difficulties would doubtless have arisen in practice from the impossibility of producing water gas continuously, and the inventor afterwards turned his attention with more success to the generation of this gas for metallurgy. From 1846 to 1881 Sir W. Siemens took out a series of patents for internally fired engines. The last, shown at Fig. 108, designed not long before his death, exhibits his matured views on the subject. Strictly speaking, it is neither a gas nor an oil engine, but both combined, the gas used as the working agent being mixed with light petroleum spirit, to make it ignite more readily. The engine which, like the Brayton, exhibits the principle of combustion at constant pressure, stands really in a separate class as a "regenerative" engine, and although never worked, it is valuable as indicating possibly on what lines the heat engine of the future may be improved.

**Siemens' Regenerative Engine.**—Fig. 108 shows a sectional elevation of the Siemens' Regenerative Engine. There are two motor cylinders, A and $A_1$, working vertically through the connecting-rods C and $C_1$, upon the crank shaft K at an angle of 180° apart. The pistons are solid, and lined on their upper face with fire-clay, to protect them from the heat. The cylinders are practically divided into two parts. The lower in each has a water cooling jacket, W, the upper part is lined with fire-clay,

or other non-conducting material. The differential pistons compress the mixture on one face during the down stroke, while the explosive gases are expanded on the other. At the top of each cylinder are the regenerators R and $R_1$, consisting of thin sheets of metallic gauze. All the valves for admission, distribution, and exhaust are contained in a revolving cylindrical valve F, worked from the crank shaft by equal bevel wheels G. The exhaust E is at the top, above the revolving valve, through

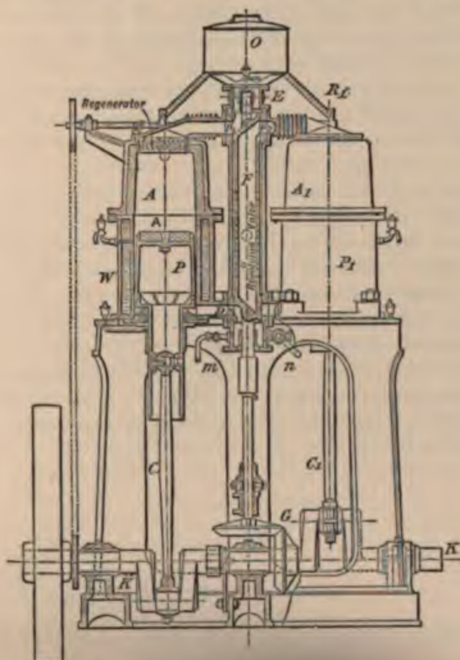


Fig. 108.—Siemens' Regenerative Engine.

which a passage at $p_1$ is opened to it alternately from either cylinder. Gas and air, mixed in the ordinary proportions, are admitted through the pipes $m$ and $n$, [illegible] opened by the rotatory movement of the valve, [illegible] of either cylinder, during one revolution [illegible] valve. The suction of the up stroke draws [illegible] stroke compresses them into a reservoir [illegible] the compressed mixture passes to the u[illegible] through the regenerator and the ports [illegible] discharged on the upper face of [illegible] forced through the regenerator [illegible]

and some of their surplus heat is stored up in it. As the fresh charge enters, drawn in by the vacuum produced by the expulsion of the exhaust gases, light hydrocarbon oil is dropped on to it from the oil tank O above. Part of the mixture of oil, lighting gas and air, heated already by contact with the regenerator, is fired by an electric spark within the cylinder, the dynamo of which is driven from the main shaft. The remainder of the charge is immediately kindled, and flows forward as flame into the cylinder, the flame being prevented from spreading back into the reservoir by the gauze diaphragm of the regenerator. The piston is driven down by the expansion of the gases, and compresses below it a fresh charge into the reservoir; during the up stroke the cylindrical valve opens communication with the exhaust. The differential pistons are deep, and the parts in contact with the cylinder walls touch only the cooler jacketed portion.

Two ingenious and economical ideas are embodied in this engine. Some of the heat of combustion is stored in the regenerator, and imparted to the fresh charge, and inflammable oil is used to mix with the gas, and render it easier to ignite. Neither of these innovations has hitherto been applied to any extent in practice to gas or oil engines. This regenerative engine of 1881, however, may be considered as illustrating Sir William Siemens' latest ideas upon heat motors. It exhibits the outcome of the mature study of a man of scientific genius, and the direction in which he thought the problem of heat engine efficiency should be solved.

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## CHAPTER III.

## THE PRIESTMAN OIL ENGINE AND YARROW SPIRIT LAUNCH.

CONTENTS.—Requisites of Oil Engines—The Priestman—Spray Maker—Vaporiser—Governor—Applications—Trials—Petroleum Spirit—Evaporative Power—Zephyr Spirit Launch.

IF Otto can claim the honour of having made the gas engine a practical working success, after the efforts of Lenoir, Hugon, and others, the same credit belongs to Messrs. Priestman as regards oil engines. Long before the introduction of their motor into this country, oil engines had been designed and worked, but there was a prejudice against them, because of the inflammable petroleum spirit with which they were chiefly driven. The Brayton, the only engine using non-explosive petro-

leum, had never become popular, owing probably to the imperfections in its cycle, its extravagant consumption of oil, and low mechanical efficiency. Whatever the cause, oil engines were scarcely known or used until the appearance of the Priestman in 1888. About this time Messrs. Priestman acquired Etève's patent, and their oil motor was introduced at the Nottingham Agricultural Show in the same year.

**Requisites of Oil Engines.** — In any engine intended to supply the deficiencies, and remedy the drawbacks of gas or steam, the following points must be considered. It should be— I. Self-contained and quite independent, having everything requisite for its efficient working for a certain length of time. II. Safe and simple, using as the working agent a combustible which is neither difficult to procure, nor dangerous to transport. III. Easy to handle, so that any ordinary unskilled workman can drive it. This is advisable, because these engines are frequently placed in the hands of labourers without any knowledge of machinery. IV. Compact, and easily transported from place to place. V. Economical in working.

These conditions are found in the Priestman engine, which is well adapted for all kinds of industrial operations requiring small powers. In many country places where gas cannot be procured, and abroad where coal is scarce and dear, it has probably a great future before it, because it uses only common petroleum, which can be had everywhere. Coal is generally required in gas and steam engines, and in many countries it is obtained with difficulty. The store of petroleum is practically unlimited, and fresh sources are continually being opened up in different countries.

**Priestman.**—This oil engine uses almost any kind of heavy petroleum, but it is not suitable for light volatile spirit. It works best with common petroleum, having a specific gravity of 0·800, and flashing point 100° F., but it may also be driven with heavy Scotch paraffin, of 0·820 specific gravity, and flashing point 150° F. Even common creosote of still lower density is available, but there are practical difficulties in the way of using it. Of course, the heavier the oil the thicker will be the residuum, and the more carbon is deposited inside the engine, the oftener it must be cleaned. Nor can these very heavy oils be properly treated in an engine cylinder, by raising the temperature. If the oil is too much heated, it is converted into oil gas instead of vaporised spray, and tarry deposits accumulate in the working parts. The proper temperature of the charge of oil vapour and air on entering the cylinder has been determined by experiments at from 170° to 300° F., according to the size of gine. The proportions are 191 cubic feet of air to ·015 cubic f oil vapour for a 1 H.P. engine.

109 gives an elevation, and Fig. 110 a sectional view of

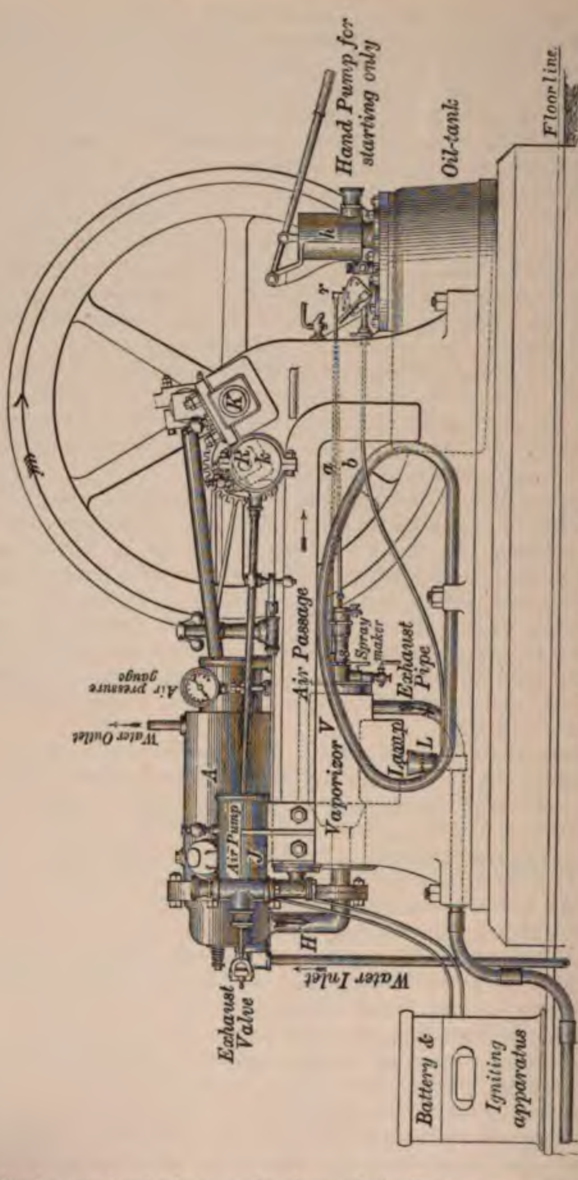


Fig. 109.—Priestman Oil Engine.

the cylinder, water jacket, and valves of the Priestman oil engine. Both drawings, as well as several of the following details, are

taken from Professor Unwin's paper in the Proceedings of the Institution of Civil Engineers, vol. cix., 1892. The horizontal motor cylinder, A, is divided from the compression space, C, the proportional volumes of the two being—clearance or compression, 88 cubic inches; volume described by the piston, 191 cubic inches, for a 1 H.P. nominal engine. The piston P works on to the crank shaft K through a connecting-rod. At the

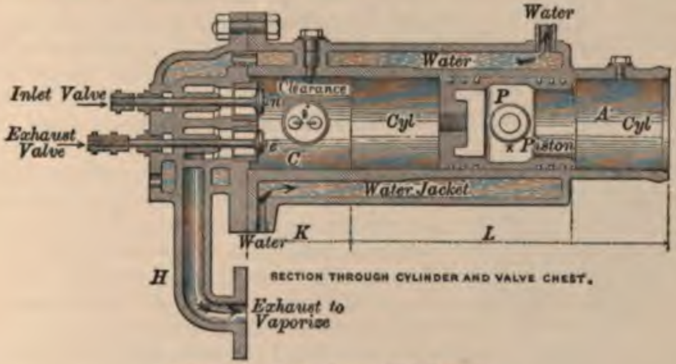


Fig. 110.—Priestman Oil Engine.

back of the cylinder are two valves, inlet and exhaust, as shown in the drawing, Fig. 110. The exhaust is worked by an eccentric, *k*, on the auxiliary shaft, R, Fig. 109, revolving at half the speed of the crank shaft, to which it is geared by wheels in the usual proportion. In the Priestman, as in most other oil engines, ordinary lift valves are used, of a simple type. Unless almost perfect combustion is obtained, there is much more deposit than in gas engines. The simpler the valves, the less liable they are to become clogged.

**Spray Maker.**—The most important parts of the engine are the vaporiser and spray maker, shown below the cylinder (Fig. 109). The oil tank in Fig. 109 is under the crank shaft, and when full, is sufficient to last for two or three days. A glass gauge shows the level of oil. A small air pump, J, is worked by the eccentric *k*, which also drives the exhaust valve. The air to supply this pump is filtered through gauze and cotton wool, and is then compressed into the oil tank at a pressure of 8 to 15 lbs. per square inch above atmosphere. This pressure forces two streams of oil and air at *a* and *b* into the spray maker S, from whence they are injected into the vaporiser V. The oil is drawn from the bottom of the tank, the compressed air from top, above the level of the oil, and both pass out through a cock, *r*. When this cock is set upright, the supply of the spray maker is cut off; when the cock is turned

to the right they are admitted, and when set to the left they pass to a small lamp, L, below the vaporiser, used to heat it when starting the engine.

The spray maker is one of the most ingenious parts of the motor. The oil and air from *a* and *b* are injected into the vaporiser through two concentric nozzles, as seen at Fig. 111. The pulverisation of the oil and its complete mixture with the air depend on the shape of the nozzles, and their exact form has only been determined after numerous experiments by Messrs. Priestman. Fig. 111 shows the latest type. The oil passes through the central tube in a small stream, and on being ejected from the mouth of the nozzle, spreads out in a fan shape. The annular air nozzle surrounds the central oil orifice, and the air is turned back with considerable force to meet the issuing oil at more than a right angle, the result being that both are violently driven out in a spray as fine as is required. Fig. 112 shows the spray maker at its entry into the vaporiser, the method of regulating the supply by the governor, and of admitting the air necessary for the dilution of the charge. The oil and air from the spray maker enter at the pressure of the air pump. At the same time the in stroke of the motor piston lifts the non-return valve G, and draws into the vaporiser a supply of air from outside through the throttle valve F. This auxiliary charge enters round the oil and air admitted from the spray maker, and passes through a number of fine holes, *d d*, in the circular air passage of the vaporiser *b b*, and a filtering layer of cotton wool. The sudden inrush of fresh air sweeps forward the oil and air with it into the cylinder.

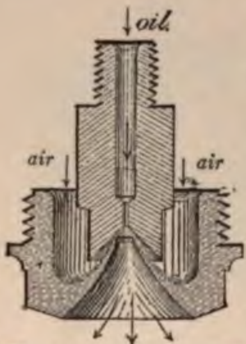

Fig. 111.—Priestman Oil Engine—Spray Maker.

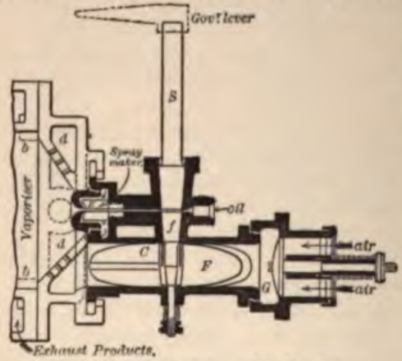

Fig. 112.—Priestman Oil Engine—Vaporiser.

**Vaporiser.**—The vaporiser is divided into two parts. In the first and compressed air are mixed with, and broken up air admitted through F; in the second the charge pletely vaporised by the heat from the exhaust gase

at a temperature of about 600° F., are led through pipe H, Fig. 109, round the vaporising chamber, before being allowed to escape into the atmosphere. Thus there are two admissions of air—one to the spray maker under pressure from the oil tank, the second at atmospheric pressure to the vaporiser through F. In each case the oil is sprayed, and is thus twice pulverised before its actual vaporisation by heat begins. Unless the heat from the vaporiser were also applied to the oil spray, it would condense and separate from the air, before reaching the cylinder. The vaporiser is contained in the frame of the engine, under the cylinder, as seen at Fig. 109.

**Governor.**—The speed of the engine is regulated by means of the spindle S above the throttle valve. It contains a small V-shaped opening at *f*, through which the oil is admitted from the tank to the spray maker, and the wing of the valve F is keyed to the lower part of the same spindle. The size of the sharp end of the V, which is presented to the passage of the oil, can be exactly regulated to admit a given quantity. If the speed is too great, the centrifugal governor, which is connected to the spindle by levers, drives it down, and partly contracts the opening *f* admitting the oil from the tank. At the same time it acts upon the throttle valve, and reduces the quantity of outer air passing to the vaporiser. Thus the governor acts by diminishing the strength of the explosions, not by cutting them out altogether, and the proportions of oil and air are always the same per stroke. As no explosions are ever missed, the engine works with great regularity.

The charge, after being thus converted into spray and completely volatilised, passes through the automatic admission valve *n*, Fig. 110, to the back of the cylinder. Here the usual series of operations carried out in internal combustion engines of the four-cycle type, takes place. The first out stroke draws in the air through the throttle valve F; the charge is then mixed in the vaporiser, passes through into the cylinder, and the next back stroke compresses it into the space C. As the inner dead point is reached, the mixture is fired by the electric spark, the explosion drives out the piston, and during the next back stroke, the exhaust gases are discharged through the valve *e*, opened by the eccentric, into the jacket round the vaporiser, and thence to the atmosphere.

**Ignition.**—The electric spark for firing the charge is generated in a battery shown to the left in Fig. 109. Many oil engines [illegible] this method of ignition, and its advantages over the hot [illegible] are, in this class of motor, very great. The spark [illegible] powerful, ignition more certain, and it is also safer, [illegible] there is no risk of previous explosion. Since there must [illegible] be a certain amount of inflammable oil vapour generat[illegible] working heat of the engine, premature ignitions mig[illegible]

with other methods; with electricity there is no such danger. In the Priestman engine the electric spark is produced in the igniting plug *i*, inside the compression space, Fig. 110. Two platinum wires are conducted from the battery to this plug, where they are insulated in porcelain tubes; contact is established at the right moment by a projection on the eccentric rod, and an intermittent spark is produced.

The shaft R driving eccentric *k* has three functions to perform. It causes the electric ignition of the charge; it works the valve *e* to open the exhaust, and it drives the small air pump J, through which the oil and air are sent from the tank to the spray maker. A small hand pump, seen in Fig. 109 at *h*, is used to pump air into the oil tank, before the engine is at work. To start, all that is necessary is to work the handle of the pump, and to turn the six-way cock, that a supply of oil from the tank may reach the lamp L below the vaporiser. When the lamp is lit, a few turns by hand are given to the flywheel, to draw a charge into the cylinder, the electric current is switched on, and the engine begins to work. The oil tank and vaporiser are easily accessible through the opening in the frame.

Although the pressure with petroleum vapour rises more rapidly than with gas, the curve of pressures, shown by the indicator diagram of the Priestman engine, does not rise as high as in gas motors, owing partly to the larger compression space. One of the advantages of the engine is that it requires no lubrication. A small portion of the oil is condensed during the compression stroke, and deposited upon the inner surfaces of the cylinder. This oil is never burnt, but forms a layer of grease, and effectually lubricates the engine, no other oiling in the cylinder being needed. As the fuel used is heavy mineral oil, it is not inflammable. Some interesting experiments to prove this have been made by Professor Robinson, who exhibited an engine before the Society of Arts in May, 1891, in which the air was shut off from the vaporiser, and oil injected alone. A lighted match held to this oil jet would not ignite, but it was readily fired as soon as the air was again admitted, to divide and break it up.

**Applications.**—Although only brought out in 1888, the Priestman engine has already been applied to many purposes. The first portable oil engine of 6 H. P. was exhibited at the Jubilee Meeting of the Agricultural Society in 1889. In this and similar engines, the motor is made complete in itself by the addition of a tank, the water from which is circulated in the cylinder jacket by a pump, driven by an eccentric on the same shaft as the exhaust valve eccentric. As a portable locomotive engine to replace steam, the Priestman has already been found of great value. The small bulk of oil and its great heating value make it suitable for marine work, when the danger of storing is minimised by using heavy oil. A vertical double cylinder

5 H.P. engine of this type has been fitted up on board a steam launch. It runs at 250 revolutions a minute, has a cylinder diameter of 7 inches, with 7 inch stroke. The construction and working are similar to those of the horizontal single cylinder motor already described, except that with two cylinders an explosion every revolution is obtained. The engine can be reversed or stopped by a hand wheel acting on the main driving shaft, and is very easily worked. Hitherto these and other types of Priestman engines have only been made for small powers, but larger sizes will no doubt be produced in time. They are also used as motive power for barges, of which there are two on the Manchester Ship Canal, driven by a 10 H.P. Priestman oil engine. The fog signals on the Point of Ayr and Corsewall lighthouse stations are worked by three 5 H.P. engines, compressing the air to 40 lbs. per square inch. Each engine uses 6 pints of oil per hour. Another installation is at Oxö in Norway, where an 11 H.P. engine compresses air to 60 lbs. per square inch. The oil used is of 0·82 density, and the consumption 11 lbs. per hour.

**Trials.**—Several excellent trials have already been made on this engine, chiefly by Professor Unwin. In 1889 he tested at the Agricultural Show at Plymouth a 5 H.P. horizontal Priest-

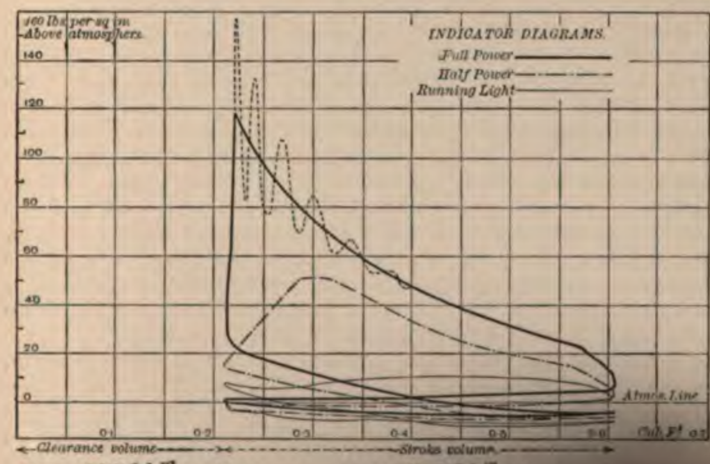


Fig. 113.—Priestman Oil Engine—Indicator Diagram.

man motor of the newest type, with $8\frac{1}{2}$-inch cylinder [illegible] stroke. Five trials were made with two kinds [illegible] care was taken to ensure accurate results. In [illegible] American oil, "Royal Daylight," was used, [illegible] flashing point 77° F., and heating value [illegible] per lb. The four other trials were made [illegible]

density 0·822, flashing point 86° F., and calorimetric value taken at 19,500 B.T.U. per lb. Fig. 113 gives a diagram taken during the trials with Russian oil. In trials at full power the following results were obtained:—

RESULTS OF TRIAL BY PROFESSOR UNWIN ON A 5 H.P. PRIESTMAN ENGINE.

| Name of Oil. | No. of Revolutions per Minute. | Mean Efficient Pressure Lbs. per Sq. Inch. | B. H.P. | I. H.P. | Mechanical Efficiency. | Oil Used per B.H.P. | Oil Used per I.H.P. |
|---|---|---|---|---|---|---|---|
| | | | | | | Lb. | Lb. |
| American "Daylight," . . | 204 | 53·20 | 7·72 | 9·36 | 0·82 | 0·84 | 0·69 |
| Russian, . . | 207 | 41·38 | 6·76 | 7·40 | 0·91 | 0·94 | 0·86 |

The heat expenditure was as follows:—Heat utilised, 16·12 per cent.; carried away in jacket water, 47·54 per cent.; in exhaust gases, 26·72 per cent.; lost by radiation and unaccounted for, 9·61 per cent. The engine was examined at the end of the trials, and found to be perfectly clean and free from smoke or deposit, and the points of the electric wires were not coated with carbon.

Another trial was carried out on a 5 H.P. Priestman engine by Professor Unwin at Hull in December, 1891. The same oils were used as before—namely, Russolene and American Daylight—and tests were made, as in the other trials, with the engine running at full power, half power, and light. The trials with full load lasted nearly three hours. With Russian oil the mean speed was 208 revolutions per minute, mean pressure 41·38 lbs. per square inch, B.H.P. 6·76, I.H.P. 7·40, and the mechanical efficiency 0·91. The consumption of oil was 0·94 lb. per B.H.P., and 0·86 lb. per I.H.P. per hour. With the American oil slightly higher results were obtained. Details of these experiments will be found in the table at p. 404. Two trials at full and half power were made on a semi-portable $4\frac{1}{2}$ nom. Priestman engine, by Professor Unwin and Mr. Pidgeon, at the Plymouth Agricultural Show in 1890. They differ very little from those already given, except that Broxbourne Lighthouse oil was used, of 0·810 density, and having a heating value of about 19,000 T.U. per lb. In the full power trial, the engine indicated 5·24 H.P., B.H.P. 4·49, cylinder 8·5 inches, and 12 inch stroke. The mean pressure was 33·96 lbs. per square inch, consumption of oil 1·06 lb. per I.H.P. and 1·24 lb. per B.H.P. per hour. In all these trials the amount of heat supplied, and the different items of heat expenditure were carefully noted. Full particulars will be found in Professor Unwin's paper already quoted.

Another trial was carried out in 1890 by Mr. W. T. Douglas

on a nom. 25 H.P. double-cylinder Priestman engine, driving an electric plant. The B.H.P. was 25·5, and the oil consumed per B.H.P. per hour 0·88 pint. The progressive decrease in the oil consumption per H.P. in these engines, as shown yearly at the Royal Agricultural Society's meetings, is striking. In 1888 1·73 lb. of oil was required per B.H.P. per hour, in 1889 1·42 lb. At Plymouth the consumption was 1·24 lb., and in the latest trials by Professor Unwin in 1891 0·94 lb. per B.H.P. per hour. These results obtained at Agricultural Shows are satisfactory, because the advantage of this motor is chiefly as an agricultural portable engine, in fields and other places where gas and steam are not available.

**American Type.**—The engine has been taken up by a firm in America, where oil is very cheap, and there is a great demand for machinery for light work and electric illumination. The type there made resembles the straight line steam engine of Professor Sweet. Professor E. Thompson of America uses pure silver igniter electrodes, in lieu of platinum, as in the English engines. He considers them better, and the wires do not get blackened or coated. These silver contacts have been at work for several weeks without cleaning. His oil engine is started with gas, which is more convenient than oil for the lamp, and it runs at about 260 revolutions per minute. Another American authority using the Priestman engine had trouble with the internal passages and back of the cylinder, which became choked with soot, until pure air, instead of air not filtered, was admitted. The engine in this case was used for pumping water from a mine.

Up to the present time Messrs. Priestman make their engines in 10 sizes, 1 to 25 H.P.; a 5 H.P. nominal has a cylinder diameter of 8½ inches, with 12-inch stroke. The two largest sizes of the horizontal types are with double cylinders only, the others are single cylinder engines. These are chiefly for land motors. The engines run at from 220 revolutions for smaller sizes down to 160 revolutions for larger. The marine type of engine is made vertical, in four sizes and with double cylinders, from 2 to 25 nominal H.P., and runs at from 270 to 220 revolutions. For portable engines, 3 single cylinder types are made, from 5 to 11 nominal H.P., running at about 170 revolutions per minute. Messrs. Priestman have already constructed from 400 to 500 engines.

**Zephyr Spirit Launch.**—The Yarrow "Zephyr" spirit launch stands in a different category to all [illegible] engines, because it is the only motor using pure and [illegible] petroleum spirit, having a density of 0·68, and [illegible] the same way as steam. Sometimes the spirit [illegible] the fuel. Its evaporative power, and therefore [illegible] is [illegible] great as ordinary kerosene, about 12 [illegible] higher

pressure for a given temperature than steam, as shown by Professor Robinson's tests. At a temperature of 155° F. it has a pressure of 10 lbs. per square inch. At 212° F. (the temperature of boiling water) its pressure is 40 lbs. per square inch, while at 300° F., with steam equal to 50 lbs. pressure per square inch, petroleum spirit has a pressure of about 115 lbs. It is easily evaporated, and may be cooled without condensing to a temperature of 130° F. Thus the range of temperature is greater, for the same pressures, with petroleum spirit than with steam, and since efficiency depends theoretically upon this range, more work should be obtained under similar conditions.

The following table exhibits the results of tests undertaken by Messrs. Yarrow, to determine the relative power of steam and of petroleum spirit, when evaporated in a boiler. The fuel used under the boiler in both cases was gas, the consumption of which was measured by a meter.

TABLE OF COMPARATIVE WORKING RESULTS OF STEAM AND PETROLEUM SPIRIT.

| Boiler Experiment. | Steam Evaporated. | Spirit Evaporated. |
|---|---|---|
| Gas consumption in cubic feet per hour, . . | 82·20 | 83·48 |
| Mean pressure of spirit in coil (lbs. per sq. inch), | ... | 55·80 |
| ,, speed—revolutions per minute, . . | 312·6 | 552·2 |
| ,, pressure in boiler (lbs.), . . . | 37·99 | 30·07 |
| Tension on brake in lbs., . . . . . . | 1·154 | 1·222 |
| Work obtained on brake in ft.-lbs. per minute, | 2524 | 4722 |
| Work in cylinder ,, ,, ,, | 5199 | 11975 |

**Evaporation of Petroleum Spirit.**—As petroleum spirit evaporates at a lower temperature than steam, less heat is put into it to raise it to the same pressure; in other words, if the same amount of heat be applied to it as to steam, a much higher pressure and more work are produced. But as less heat is required to evaporate it, less heat is withdrawn in the exhaust; the quantities of heat both imparted and abstracted are smaller than with steam, for a given amount of work. At atmospheric pressure nine times as much spirit as water will be evaporated by the same amount of heat, but the spirit being very volatile, it does not increase as much in volume, and only expands to one-fifth the volume of steam. As a working agent petroleum vapour turns more heat to account than steam; the one serious drawback is its inflammable nature, and difficulty of storage.

**Zephyr Launch.**—In the "Zephyr" launch, the spirit is introduced into a spiral coil enclosed within a casing of non-conducting material, called the vapour generator, to which heat is applied. In its passage through the coil the spirit is evaporated,

and passing into the cylinder drives the piston forward by its pressure. The exhaust products are discharged by the action of the engine into two cooling pipes, where they are liquefied and forced back to the supply tank, an air-tight copper vessel in the bow of the ship. Thus the same spirit is used over and over again, with very little waste, and the working principle and action are similar to those of a surface condensing steam engine. The risk of explosion from the inflammable spirit is also greatly reduced, since it passes through a complete closed cycle of operations, and is never brought in contact with the external air. The danger is also avoided of storing a large quantity of petroleum spirit; a small amount is sufficient, if used continuously in this way, to produce power for many hours. A small "Zephyr" launch, 36 feet by 6, running at 8 miles an hour, can carry fuel enough for 200 miles. The action of the engine is first utilised as a pump, to force the spirit from the tank to the vaporising coil, and then to drive the exhaust vapour back to the tank.

The process of heating the spirit, or generating the vapour in the copper coil, presents greater difficulties. There are two ways of obtaining this heat. The simplest method is to use part of the petroleum spirit as fuel, as well as working agent. Sometimes it is allowed to pass through a valve to a ring gas burner under the coil, ignited in the usual way, and the flame evaporates the spirit above. A constant supply being maintained, with a proper proportion of air, the flame burns steadily, and the heat is continuously generated. This arrangement has the great disadvantage of requiring the storage of a large quantity of the dangerous spirit to feed the burner, although in the coil itself only a comparatively small portion is needed, to replace the loss by leakage. A much better plan, and that generally adopted, is to use ordinary heavy petroleum, which can be stored without danger, to heat the spirit. A small air-pump driven by the engine forces air into the oil tank, and a mixture of oil vapour and air is injected as spray into the fire box or furnace beneath the coil, in the same way that liquid fuel is broken up, injected and burnt under a locomotive boiler. After being completely vaporised by the heat, it is mixed with more air, and burns with a continuous flame like a Bunsen burner. With this method there is little risk of explosion, but a separate tank is required for the mineral oil, and power to drive the air-pump, diminishing slightly the total useful work of the engine.

In the Zephyr spirit launch the engine and spirit generator are carried in the stern of the boat, and the spirit supply in the bow, to balance the vessel, leaving the [illegible] for goods and passengers. The machinery is very light, [illegible] engine, tank, &c., weigh only 1 ton in a boat 36 feet lo[illegible] class of engine is specially adapted for small launch[illegible] boats, but is unsuitable for large powers or great [illegible] It can easily be

started in from two to five minutes after lighting the burner, and like other vessels driven by petroleum, the Zephyr spirit launch is smokeless. The consumption of fuel for burning is about one-third of a gallon per H.P. per hour.

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## CHAPTER IV.

## OTHER OIL ENGINES.



**Classsification.**—The Priestman oil engine is at present one of the few motors adapted for driving only with oil. Most other oil engines were originally constructed to use gas as the motive power, and the oil carburetting apparatus has been added afterwards. All oil motors, however, including the Priestman, employ the usual gas engine cycle, the series of operations proposed by Beau de Rochas and adopted by Otto, comprised in four strokes of the piston, with one explosion every two revolutions. Excellent results are obtained with this cycle, and the engines work more smoothly than gas motors, owing to the perfect lubrication afforded by the oil. The action and method of utilising the power developed does not differ from that hitherto described. The difference consists in the treatment of the petroleum. In no two motors is the process of burning the oil precisely the same, though in all it is sprayed or broken up by the addition of air or steam, and vaporised by applying heat. The following classification, given in *The Engineer* of June 24th, 1892, of the methods by which the oil is evaporated, may be found useful:—

**Spray maker.**

1. Engines in which the oil, before entering the cylinder, is converted first into oil spray, forming an oil shower, and next into vapour in a hot chamber.

**No Spray maker.**

2. Engines in which the liquid oil is injected into a prolongation of the engine cylinder, a hot cartridge chamber or combustion space, where it is converted into vapour or gas.
3. Engines in which the oil is converted into vapour or gas in a chamber contiguous to the cylinder, and communicating with it by a valve.
4. Engines in which the oil is converted into vapour or gas in a separate chamber, heated apart from the cylinder.

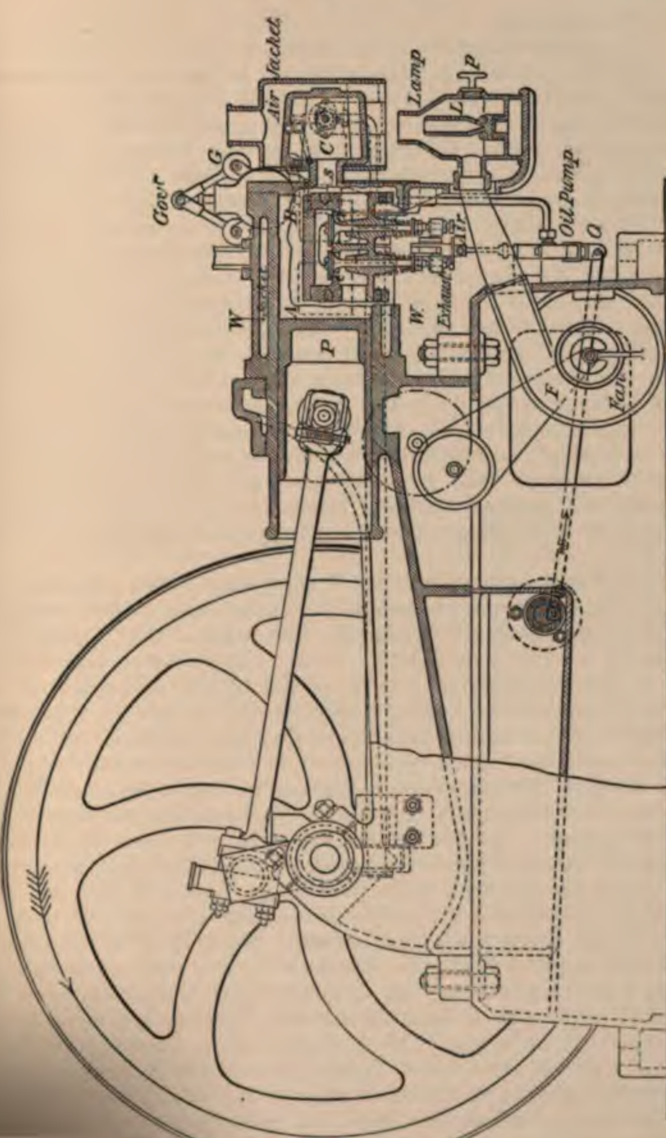


Fig. 114.—Hornsby-Akroyd Engine—Sectional Elevation.

red for use is fired in one of the three

1. By electricity.
2. By a tube heated by an oil flame.
3. By spontaneous ignition of the oil vapour, due to its compression, and to the heat of the vaporising chamber.

The **Hornsby-Akroyd** oil engine has one peculiarity which distinguishes it from the other heat motors hitherto described. It has neither hot tube, electric spark, nor slide valve with flame, but the charge is fired according to the method described in the third division above. The oil is injected into a red hot chamber (or cartridge) at the back of the cylinder, into which heated air, compressed by the back stroke of the piston, is forced as it reaches the inner dead point, and the mixture ignites spontaneously. The internal surface of this chamber is provided with radiating ribs, to afford a greater heating area. It is maintained at a red heat by the combustion and explosion of the oil and air at every other stroke. The engine is of the usual four-cycle type, and the functions of admission, compression, explosion plus expansion, and exhaust are carried out during four consecutive strokes. The Hornsby-Akroyd is perhaps one of the simplest oil engines hitherto produced. Its action and the method of vaporising the oil will be best understood from Fig. 114.

Here A is the motor cylinder, P the piston, B the compression space, into which the piston does not enter, and C the cartridge or combustion chamber beyond it. The walls of the cylinder are cooled by a water jacket shown at W, but the combustion chamber C is surrounded only with an air jacket, to keep it at a uniform temperature. The highly heated charge in it is prevented by the intermediate compression space B from coming in contact with the cooler cylinder walls. Below is the lamp L used to heat the combustion chamber or vaporiser at starting. The oil for this lamp is drawn from the same tank as that feeding the engine. Air is admitted above it from a fan, F, worked by hand. A small piece of asbestos or other absorbent material is pushed through the little plug at *p*, dipped in the oil and ignited, and as the air enters it rapidly fans the oil into a fierce flame, which rushes out through the hole at the top, and in a few minutes heats the vaporiser C. As soon as the latter is red hot, the current of air is stopped, the lamp extinguished, and the engine then works automatically, after a few turns of the flywheel by hand. The T-shaped air and exhaust valves, seen at *c* and *d*, are worked by cams and levers through an auxiliary shaft, geared to the crank shaft in the proportion of 2 to 1. These valves communicate with the cylinder through the same opening, in order that the heat of the exhaust products may warm the fresh air admitted through valve *d*. The temperature of the air is further raised by the heat of the cylinder, and of the back compression stroke. As the piston reaches the inner dead

point, it forces the compressed air into the red hot cartridge space, where a small quantity of oil is injected into it. The oil is drawn from a tank in the base of the engine, and a few drops are delivered by the little oil pump O at every other stroke, through a narrow tube and simple nozzle into the hot chamber C. The oil pump, worked by the same lever as the exhaust, sends the oil to the chamber in a fluid condition, and not, as in other oil engines, in the form of spray. The heat of chamber C and the pressure of the air charge immediately vaporise it; the maximum pressure of the inner dead point causes the ignition, and the piston is driven out. The burning charge passes into the compression space of the cylinder through a very small passage, *s*, that as little heat as possible may be dissipated through the walls, and the pressure of the flame increased. The exhaust is opened by the side shaft worked from the main crank. The centrifugal governor G acts on the little horizontal valve through which the oil is admitted to the vaporiser, and closes the narrow tube when the speed exceeds the normal limits. At the same time it opens a little bye-pass valve, and the oil is sent back to the tank; thus the oil pump works continuously, the governor regulating only the direction in which the oil passes. The valve box has a water jacket, to keep the oil cool till it reaches the vaporiser. The quantity conveyed to the engine to form a charge is regulated by adjusting the stroke of the oil plunger. The air being dry and hot, the engine has to be lubricated in the usual way.

**Method of Vaporisation.** — The peculiar feature of the Hornsby-Akroyd engine is that no attempt is made to vaporise the oil or convert it into spray, until it is actually injected into the combustion chamber. Hence the density of the oil is a point of no importance, and heavier petroleum may be used than in most other engines. The specific gravity of the oil is usually about 0·850, and its flashing point 150° F., but the engine will work with oil of specific gravity 0·854, flashing point 220° F., and weighing 8½ lbs. to the gallon. Thus it is one of the safest and simplest of oil motors, and these two advantages should make it popular, when better known. The quantity of oil injected at a time is very small, only about ·015 cubic inch per stroke of the oil pump in a 6 H.P. engine. The proportion of air present is so large that combustion is complete, and there is said to be no heavy residuum. The exhaust products are employed to warm the incoming air, the heat of combustion to vaporise the oil, and raise the temperature of the next charge to the ignition point. Much of the heat generated is thus utilised, while if very heavy petroleum is used as the working agent, the heat of the jacket water may be employed to keep it in a proper fluid condition. The consumption of the engine is about one pint per hour per B.H.P., [illegible] working under ½d. per B.H.P. per

hour. Fig. 115 gives a diagram of an engine indicating 6·74 H.P., taken by Professor Robinson. The specific gravity of the oil was 0·854, flashing point 220° F., and the engine made 224 revolutions per minute. The consumption of oil was about 0·9 pint per B.H.P. per hour. The engine is made by Messrs. Hornsby & Sons, Grantham, in ten sizes from $1\frac{1}{2}$ to 19 B.P., and runs at 250 to 200 revolutions per minute.


Fig. 115.—Hornsby-Akroyd Engine—Indicator Diagram.

**Trusty.**—A different method of vaporising the oil has been adopted in the Trusty engine, brought out by Messrs. Weyman & Hitchcock, of Guildford, and resembling the gas engine of the same name, with the addition of an apparatus for gasifying the oil. Some years ago an engine was invented by Mr. Knight of Farnham, in which the oil was vaporised in a jacket round the combustion chamber. The patent of this engine has now been acquired by the makers of the Trusty, who have applied and improved the principles of the early motor. In the Knight engine, ignition was obtained by making a flame, produced by the action of bellows, play at the right moment upon a coil of platinum wire. In the Trusty, the charge was at first fired by directing an air jet upon an oil flame, but this method has now been abandoned in favour of ordinary tube ignition.

The engine is horizontal and single acting, with one cylinder; the action is similar to that described in the Trusty four-cycle gas engine (p. 133). Fig. 116 gives an end view, with the method of introducing the oil into the vaporiser. The latter, shown at V, consists of a jacket fitting round the compression end of the cylinder, and divided internally into sections. The air admission and exhaust valves, S and $S_1$, are worked by levers L and $L_1$, from a side shaft gearing into the main shaft in the proportion of 2 to 1, as in the Trusty gas engine. At $o$, $o_1$, are the screws for adjusting the valves, the exhaust outlet is at E. The method of vaporising the oil is original. It is drawn through the pipe $p$ from a tank below the engine, and pumped from the horizontal pump P through the second pipe $p_1$, into the column or receiver C at the top of the engine. From here it passes into the jacket or vaporiser V through a small glass tube just above the cylinder, shown in Fig. 118, through which and through valve H it is admitted drop by dro[p]
diately vaporised. The igniting
cylinder and evaporating chambe[r]
heat by a lamp J. The rod Q

worked at M by a hit-and-miss device, controlled by the pendulum governor G. If the speed is too great, the projection on the governor cannot reach the notch on the valve rod in time, a lever D is interposed, and the oil pump does not work. The lever also acts upon the valve H, admitting the oil to the vaporiser, and the supply is thus doubly checked by the governor.

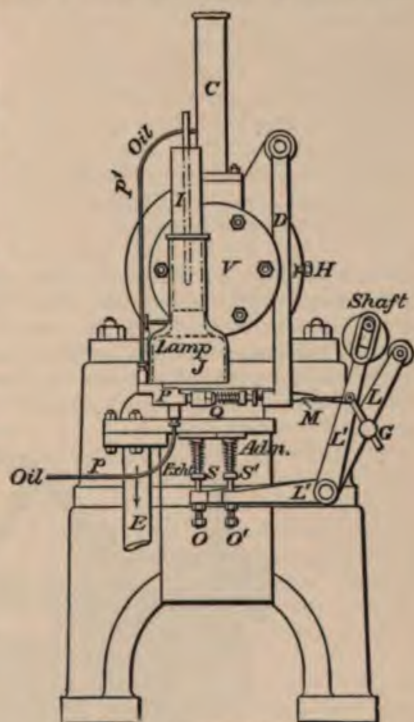

Fig. 116.—Trusty Oil Engine.

As the combustion of the charge takes place in the compression chamber, the jacket round it becomes so hot that the oil, as it enters, is instantly turned into vapour. The out stroke of the piston draws in a charge of fresh air through the admission valve $S_1$, and at the same moment, through valve H, the vaporised oil is admitted into the compression chamber from the jacket. The oil vapour and air mingle in the cylinder, and are compressed by the return stroke of the piston, driven up the tube, ignited in the ordinary way, and explosion and expansion of the charge follow. The oil is vaporised by the heat of explosion, during which the highest temperature of the cycle is reached, and greater pressures are said to be attained than in the Priestman engine, where the oil is vaporised by the heat of the products of combustion only. The Trusty engine also runs at higher speeds than the Priestman, and gives a good heat efficiency. The special feature of the engine is the vaporisation of the oil drop by drop, as it is required, the quantity being regulated by the stroke of the oil pump, which in a 4 H.P. engine is about ¼-inch diameter. As the oil is not sprayed before it enters the
density nor the varying temperature at
the working of the engine. There is
, because the petroleum is turned
t of combustion. The parts and

passages being easily accessible, the occasional cleaning required is carried out without difficulty. Broxbourne lighthouse oil, distilled from Scotch shale, with flashing point 150° F. and specific gravity 0·81, is usually employed, but a much heavier oil with flashing point 250° F. may be used.

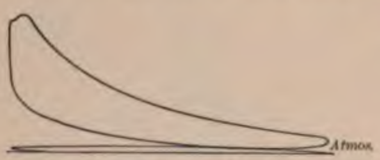


Fig. 117.—Trusty Oil Engine—Indicator Diagram.

**Trials.**—In a two hours' trial on a Trusty oil engine made by Mr. Beaumont, the specific gravity of the oil was 0·810. The engine indicated 6·2 H.P., and gave 4·28 H.P. on the brake; the mechanical efficiency was 69 per cent., and the speed 230 revolutions per minute. The oil used amounted to 0·963 lb. per B.H.P., and 0·667 lb. per I.H.P. per hour. All the items of heat expenditure were carefully noted; particulars will be found in the table at p. 404. The ratio of heat shown in the indicator diagram as work done,

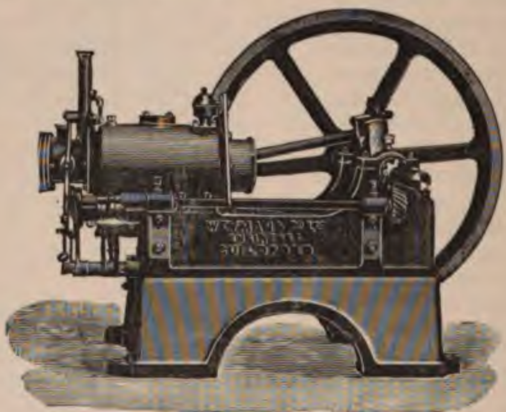

Fig. 118.—Trusty Oil Engine—External View.

to that supplied in the oil was about 20½ per cent. Fig. 117 gives a diagram taken during the trial, and Fig. 118 an external view of the engine. The maker's types range from ½ H.P. to 12 H.P. nom. in eleven sizes; the speed per minute is 220 to 180 revolutions.

**Root's Petroleum Motor.**—A small engine, in which the oil is vaporised in a new and original manner, has been used to drive a little boat running on the Thames. The engine is known as Root's Petroleum Motor, and the launch was built by Messrs. Vosper & Co., of Southampton. It

is a vertical double-cylinder engine, the crank, shaft, and connecting-rods being all covered in. The petroleum is admitted from a receiver at the top, and falls first through ports into grooves in a reciprocating bar or lever. Movement is communicated to the latter, through a series of vibrating levers, from an eccentric driven from the crank shaft by wheels. From hence the oil is led through pipes into an annular vaporising chamber in the centre of the engine. This chamber is placed above the space containing the ignition tubes, which are heated by a jet burner below them, fed with fine oil spray. One cylindrical casing encloses both the vaporiser and the hot tubes. Air enters through holes at the bottom of the vaporiser, and passing upwards is heated by the flame and the ignition tubes. It is then led off through pipes, heating all the ports and passages through which the oil filters down into the vaporiser, before it returns to the hot chamber. Thus the air, heated by the flame and hot tubes, is impregnated with the oil, and carries back a certain quantity to the vaporiser, the heat from the enclosed ignition chamber being sufficient to turn the oil into vapour. From here the charge of oil and air passes to the motor cylinders through automatic admission valves, held on their seats by springs, and raised by the pistons in their descent. The mixture is ignited, and drives down the pistons in the usual way. The exhaust valves at the top of each cylinder are worked by the same vibrating levers and eccentrics as those admitting the oil. In spite of the numerous ports and passages through which the oil has to pass, there is apparently no deposit. Drawings of this engine will be found in *The Engineer*, September 30, 1892.

**Otto.**—The Otto may truly be called the prototype of all modern gas engines, and to its many advantages has now been added that of working with petroleum, where gas is not available. In the oil motor introduced by Messrs. Crossley the usual four-cycle type is adhered to in every respect, and the engine works in the same way as with gas, except that in some cases electric ignition has been employed. Besides the ordinary parts, there is an oil pump driven from the side shaft, and also a vaporiser at the back of the engine. Two methods of volatilising the oil have been adopted. With the first, only light oil or benzoline can be used. It is stored in a small receiver, and heated by the exhaust gases, which are carried along the bottom of the receiver. The level of the oil is maintained constant by a float. Air, sucked in by the out stroke of the piston, enters the receiver, and is drawn up from the bottom of the liquid through a perforated disc, in order that it may pass through the oil in as many streams as possible. From hence the air, now carburetted, is conveyed, through a vessel filled with [illegible] to cleanse it, to the admission valve, where it is [illegible]

air drawn in from the base of the engine, before it enters the motor cylinder. The charge is fired electrically, and the spark is produced by interrupting the current from a small dynamo, by means of a projection on the distributing shaft. This method has been chiefly used in Germany.

In the more modern applications of petroleum to drive the Otto engine the use of inflammable spirit is abandoned. The oil to be vaporised has a specific gravity of 0·820 and 30° C. = 86° F. flashing point, but heavier oil, flashing at 120° F., can be employed. A current of air at considerable pressure is drawn, by the suction stroke of the piston, past a nozzle from which oil is sprayed into it. This oil is drawn by gravitation from a tank above the engine. The vapour thus formed passes into a hot chamber, and from thence into the cylinder. It is compressed by the next back stroke of the piston to a pressure of 200 lbs. per square inch, together with a charge of fresh air supplied through an automatic valve to dilute it. Ignition is

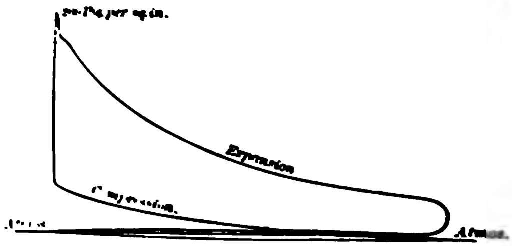


Fig. 119.—Otto Petroleum Engine—Indicator Diagram.

obtained by a tube heated by a lamp of special shape, fed with petroleum and air from a separate vessel. The pressure in this receiver can be raised by hand to about 40 lbs., and will last for a considerable time. The lamp is also used to heat the vaporiser at starting. If the speed of the engine be too great, the governor closes the admission valve, and keeps the exhaust open. The burnt products re-enter the cylinder at the next out stroke, and its temperature is therefore not much reduced. In a trial made with a 4 H.P. nom. Otto petroleum engine (diagram, Fig. 119) the B. H.P. was 5·3, the engine made 212 revolutions per minute, and consumed 0·7 gallons of oil per B.H.P. per hour. Messrs. Crossley make this class of engine in three sizes, 2 H.P., 4 H.P., and 9 H.P. nom., running at a speed of about 200 revolutions per minute.

**Griffin.**—The Griffin oil engine, lately brought out by Messrs. Griffin & Co., of Bath, must be distinguished from th gas engine, made by Messrs. Dick, Kerr & Co., of K The ordinary Beau de Rochas cycle is used, and sion every two revolutions, as in the Otto. I

cylinder horizontal engine, and the admission and exhaust valves are driven from a side shaft gearing on to the crank shaft in the usual way. The novelties claimed for this engine are the method of vaporising the oil, of ignition, and of governing. The vaporiser is placed in the bed plate, at right angles to the cylinder. The oil drawn from a tank in the base is injected into the vaporiser in the form of fine spray. The spraying jet consists of two concentric nozzles, one inside and set behind the other. The oil is injected from the inner nozzle into the outer, and the air, at a pressure of 12 lbs. per square inch, carries the fine oil particles to the vaporiser. Here they are converted into vapour by the heat of the chamber, which is surrounded by a passage containing the exhaust gases, and ribbed internally to afford greater heating surface. Much of the heat of explosion must pass into this chamber. As the oil vapour emerges from the vaporiser at the other side of the engine, it is carried through a curved pipe to the cylinder above. Below this pipe is a perforated box, through which air is drawn to mix with the charge. This air is also heated, because the exhaust gases are carried through the curved pipe, before they are discharged to the atmosphere. The charge then enters the cylinder, and is ignited by the tube, kept at a red heat by an oil spray Bunsen flame. The ignition of the charge is also original. A small quantity of oil is conveyed from the tank to a little vessel, where it is drawn upwards by capillary attraction. It is next broken up into spray by a blast of air from the air pump, and carried forward into a pipe kept at a high temperature by the heat from the burner. Here it is vaporised, ignited at the Bunsen burner, and the flame plays continually on the tube.

**Governing of Griffin and other Oil Engines.**—To regulate the speed of an oil engine by reducing the number of explosions, cutting off the supply of oil, and passing air only through the cylinder, is not altogether desirable. If there is no explosion, no heat can be communicated from the exhaust gases to the vaporiser. The latter becomes chilled, and the next time oil is admitted, the temperature is not high enough to evaporate it completely; unburnt oil passes into the cylinder, and waste and deposit of residuum are the result. In the Griffin engine the centrifugal governor acts upon two valves placed side by side, one admitting the completely mixed charge to the cylinder, the other discharging the exhaust gases, after they have heated the vaporiser and the incoming charge. If the speed is too great, neither of these valves act, and the admission of air to the vaporiser is a[illegible]so suspended. As no charge either [illegible] ere is little waste of heat. The [illegible] leum of 0·80 specific gravity, [illegible] ing the air pump is worked [illegible] med is ignited, and enters

the vaporiser as a strong flame. In ten minutes it is hot to work the engine. The air pump is then conn eccentric and side shaft driving the valves. Drawi engine will be found in *Engineering*, November 4, 18

**Weatherhogg.**—The Weatherhogg petroleum en the solitary exception to motors employing the Bea four-cycle. It is a six-cycle engine, with a scaveng air introduced and expelled between each admission o and air. The oil is injected by a pump into a vap heated by a blow-pipe flame, and in its onward pas cylinder is diluted with the proper proportion of air is by hot tube. This engine appears to be still in mental stage.

**Rocket.**—A petroleum engine called the "Rocket' been introduced by Messrs. Robert Stephenson & C castle-on-Tyne (Kaselowski's Patent). In this motor, from a tank above the cylinder flows by gravit vaporiser, where it is sprayed by an air current, and by the heat of the exhaust gases. From thence it p engine, being diluted on its way with the proper pr air. No pumps are required for the oil, &c. Hot tu is used, with a timing valve worked by a cam on th shaft. The governor is so arranged that when the no is exceeded, the supply of oil vapour is cut off, and n sion of the waste gases in the cylinder takes place.

**Lenoir.**—In later oil engines the tendency is certa heavier and less inflammable oils, as shown by the m in the Otto. In the French Lenoir motor a carburat added, in which the more dangerous lighter oils are Fig. 120 gives a view of this engine working with carbu the action is the same as in the modern Lenoir gas m position of the carburator above the cylinder is near eno heat of the engine to keep the oil in a proper fluid con counteract the cold of evaporation, but not near enou vert the oil into vapour. Hence the use of lighter which can be evaporated without much heat. The is attached to the engine, and a very slow rotatory m transmitted to it by a small strap and worm wheel

spirit soon became decarburetted, and the apparatus was consequently remodelled. In the cylinder now used, a number of small semi-circular troughs are set round the inner circumference.

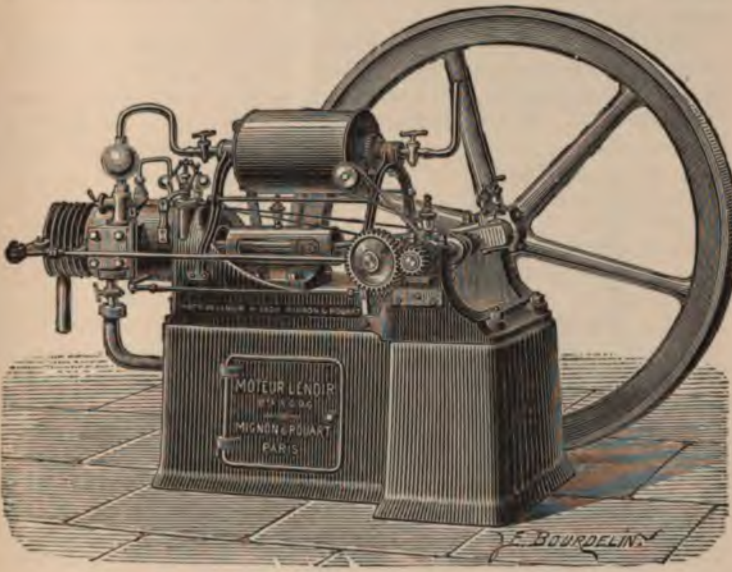


Fig. 120.—Lenoir Petroleum Engine—External View.

The bottom is half filled with gazolene, and as the cylinder rotates, the troughs pass successively through the oil, and fill themselves. Raised by the continued movement of the carburator, each in turning is emptied of its contents, which fall in a fine rain or mist back into the oil below. Thus the cylinder is always full of pulverised gazolene, thoroughly saturating the air as it passes through. The carburetted air is then conveyed to the motor cylinder through a passage or bulb, in which metallic wires are fixed, to prevent the flame from shooting back into the carburator.

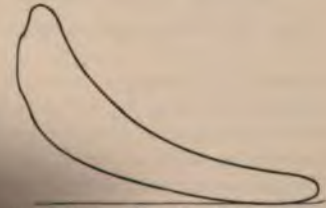

Fig. 121.—Lenoir Petroleum Engine—Indicator Diagram.

A series of careful experiments were made by M. [illegible] on a Lenoir en[illegible] carburetted air. Two engines were tested, [illegible] nom; the density of the oil used was [illegible] the B.H.P. was 1·96, and consumption [illegible] pint per B.H.P. per hour;

in the second the B.H.P. was 4·15, and consumption of oil 1·14 pint per B.H.P. per hour. The Lenoir petroleum engine has also been used for portable motors, and to propel a steam launch. Fig. 121 shows an indicator diagram taken during the second trial by M. Tresca.

**Simplex.**—The Simplex gas engine of MM. Delamare-Deboutteville and Malandin, made at Rouen, and described at p. 140, has also been supplemented by a carburator. In this apparatus the density of the oil used is rather greater than in the Lenoir, but as the heat of the engine does not vaporise it, heavy petroleum cannot be employed. Fig. 122 gives a view of the Simplex carburator, and explains the working method. R is the tank, usually open at the top to the atmosphere, and containing liquid petroleum of 0·65 to 0·70 density; D the valve for admitting it into the column E; B is a spiral horsehair brush, which breaks the oil falling on to it into spray; at C is the casing round the column, heated by the hot water from the motor cylinder jacket. This water leaves the jacket at a temperature of 60° to 70° C., and falls to 40° or 50° C. by the time it reaches the carburator, where it helps to counteract the cold produced by evaporation. F is the small cock from which water, also drawn from the jacket, falls in a light shower into the column, and mingles with the narrow stream of oil entering through D from R. The water helps to break up the oil into finer spray, and also to purify it, by holding in solution the coarser particles of dirt. The oil and water filter down through the spiral brush into the vessel L below, to which they are admitted through the valve V. Here the water and impurities are deposited at the bottom, and the water kept at a constant level by the overflow pipe N. The suction stroke of the piston draws air down from the top of the carburator through the column C, which is filled with oil spray and water, and this air, charged with petroleum vapour, is carried off from the vessel L through the pipe S to the motor cylinder. A safety valve is placed in this pipe, to

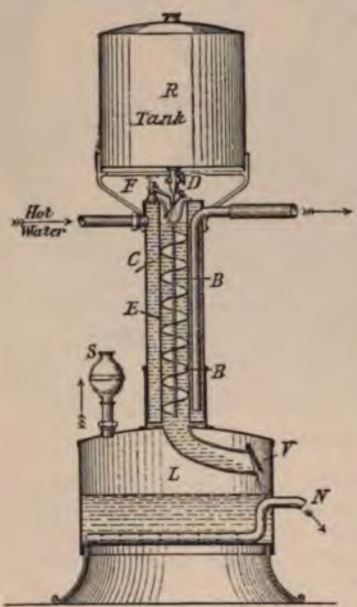

Fig. 122.—Simplex Carburator.

hinder the flame produced by the explosion of the charge from shooting back into the carburator. The hot water prevents all clogging of the valves by oil deposit, and the engine is found to work without trouble. As the electric spark is used in the Simplex engine, no difficulty is experienced in igniting the charge.

**Sécurité.**—A horizontal petroleum engine patented by MM. Diederichs (Belmont, Chabond, and Diederichs) and known as the "Sécurité," appeared at the Paris Exhibition of 1889. It is rather complicated, but is self-contained, and requires no external connections of any kind. Instead of an electric battery to fire the charge, the engine carries with it the ignition apparatus. This is an advantage in motors which are intended for use in the country, and to be handled by labourers. The "Sécurité" engine may be driven with any kind of petroleum, but the best for use is heavy mineral oil distilled from bituminous schist, of 0·82 to 0·85 specific gravity. It is the only petroleum engine, properly so called, which was shown at the Paris Exhibition. Like the Priestman, it is not a gas engine adapted to the use of petroleum by the addition of a vaporiser, but has from the first been intended to work with oil.

Fig. 123 gives a general view of the engine. Two kinds of petroleum are used, both contained in separate compartments of the reservoir T. A lighter petroleum spirit is required to start the engine, and this is one of its drawbacks; after it is at work, ordinary heavy petroleum is used. A is the horizontal motor cylinder, and R the auxiliary shaft, worked from the crank shaft by bevel wheels 2 to 1. The engine stands on a strong foundation, B, which is hollow, and part serves as a reservoir for the compressed air. The shaft R works the ignition, admission, and exhaust valves by two cams and crank levers. One lever opens the admission valve under the cylinder as shown. The centrifugal governor G is also worked from R by means of bevel wheels, and regulates the admission of oil to the vaporiser by acting upon a cock, *r*, in the oil pipe. The petroleum for working the engine is contained in the front part of the reservoir T. From hence it passes through a small pipe, *p*, and the cock *r* to the vaporiser V beneath the cylinder, in which is a coil of pipes. The exhaust gases pass into the vaporiser at E, and heat the petroleum, which in its passage through the coil becomes completely vaporised. It is then led out through a nozzle at the bottom, and injected into a pipe, F, leading to the admission valve of the cylinder. As it is already at high pressure and temperature, the suction of the oil spray jet draws in with it a current of atmospheric air from below the vaporiser at N, and the two become thoroughly [illegible] pass on to the cylinder. If the speed be too [illegible] governor rise, and act upon the pipe *p*, clo[illegible] enters the vaporiser, and

consequently only fresh air is drawn into the cylinder by the next out stroke of the piston.

The ignition apparatus is somewhat complicated, but has the advantage of requiring no battery, or gas to heat the tube. Petroleum essence, much lighter than the oil used for driving the engine, is contained in the vessel U above the cylinder. At P is the pump immediately below the crank shaft, and driven from it by an eccentric, through which air is pumped by the pipe $b$ into a compartment in the hollow base of the engine, B, and from thence through $b_1$ to the vessel U. The hand pump C

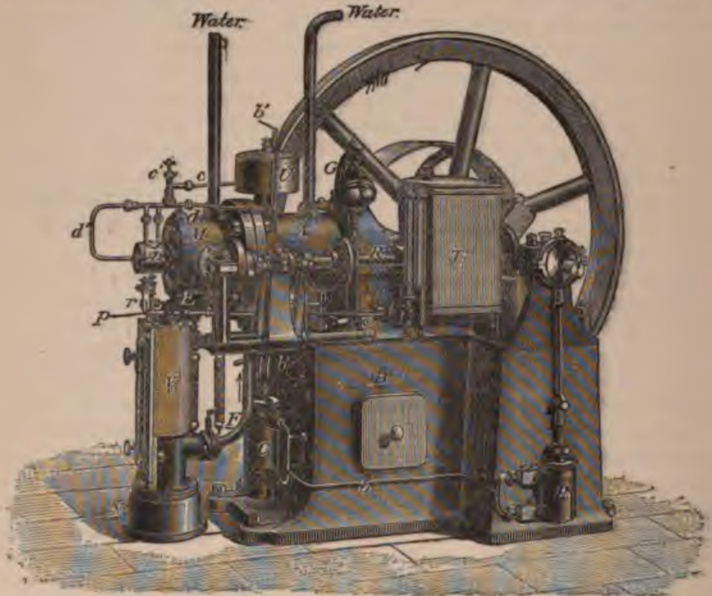


Fig. 123.—Moteur Sécurité—External View.

is used to compress the air into the reservoir when starting the engine. The pressure of this air in the vessel U forces the petroleum essence along the pipe $c$, past the cock $c_1$ adjustable by hand, and it falls drop by drop into a current of compressed air conveyed in the branch pipe $d$ from the air pipe $b_1$. The two are carried through pipe $d_1$ into the compression space M at the back of the motor cylinder A. Before reaching the burner, the highly inflammable carburetted air is heated by passing it through a small coil of pipes, $d_2$, kept at a high temperature by the heat from the cylinder. The burner consists of a small platinum capsule maintained at a red heat by a carburetted air flame. The charge in the cylinder, compressed by the back

stroke of the piston, is ignited on reaching the capsule, and explosion and expansion follow. Communication is established between the cylinder and the igniting chamber M by a plug worked from the side shaft, which uncovers the small passage between them at every other revolution. The cylinder is kept cool by a water circulating jacket, as shown in the sketch. The consumption of oil is said to be about 1 pint per H.P. per hour.

**Ragot.**—Another oil engine shown at the Paris Exhibition

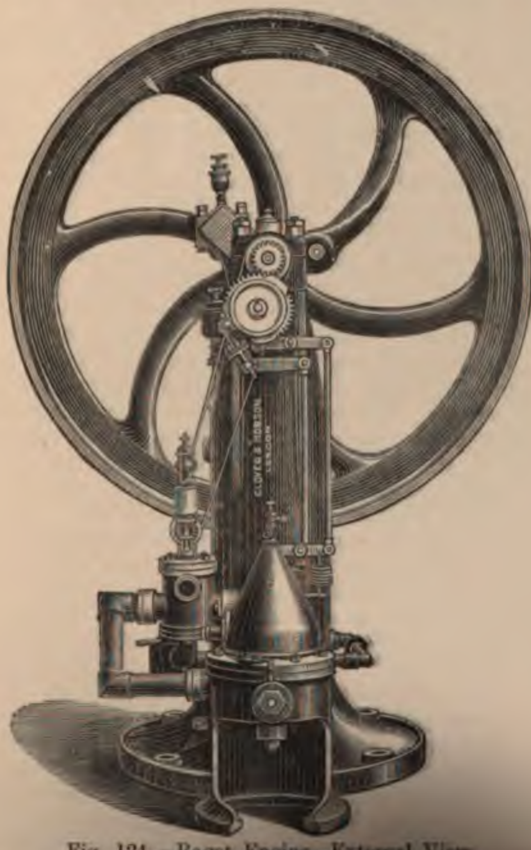

Fig. 124.—Ragot Engine—External View.

of 1889 was the Belgian "Moteur Ragot," the only engine competing with the "Sécurité." It was [illegible] intended, like most other oil engines, to be driv[illegible] vapor-iser added by the inventor, for [illegible] not available. The Ragot engine is [illegible] in its

method of ignition and of vaporising the oil. It uses heavy petroleum, having a density of 0·800 to 0·820, and the consumption of oil is said to be only about ¾ pint per H.P. per hour. Fig. 124 shows a view of this compact little vertical engine. The crank and motor shaft are at the top of the cylinder, and the piston works on to them through a connecting-rod; the oil vaporiser and pulveriser are seen below the cylinder. Upon the motor shaft is a small pinion wheel and pulley. The pulley works the centrifugal governor; the wheel gears into another, below it, of twice the diameter, from which the admission and ignition valves are worked by means of cams and levers, as shown in the drawing. The ordinary four-cycle is used, and there is an explosion every other revolution. The charge is fired electrically, and the cylinder cooled by a water jacket in the usual way. The chief peculiarity of the engine is the vaporiser, consisting of two hollow cones, of different proportions, fitting one over the other, with a space between them. Into this space the oil is dropped from a small receiver, communicating through a pipe with an injector or nozzle. The suction of the motor piston draws a small quantity of air into the nozzle, with the oil, and the two fall together into the space between the cones. Here the oil is pulverised and the air heated. The gases of combustion are admitted from the motor cylinder into the inner cone, and by their heat convert the oil above into vapour. Through a small pipe establishing communication between the cone and the cylinder, the oil spray and air are drawn, by the slight vacuum produced by the out stroke, into the mixing chamber, where the oil is further vaporised, and diluted with fresh air to render it explosive. The exhaust gases are also carried round this chamber before passing to the atmosphere. The charge is compressed by the return stroke of the piston in the ordinary way, and fired by an electric battery. The admission valve is controlled by the governor, and the strength of the charge, not the number of explosions, varies according to the speed. In the semicircular space below the vaporiser a lamp, fed with ordinary petroleum, is placed to heat it when starting, and in from 10 to 15 minutes the engine begins to work. The process can be quickened by introducing a few drops of petroleum essence or gazolene into the vaporiser. The "Albert" petroleum motor, made by Messrs. Glover & Hobson, is a reproduction of the "Ragot." Although handy and compact, this little motor does not seem to have been very successful.

**Tenting.**—A few other French engines are arranged to work with petroleum, where lighting gas cannot be had. In the Tenting engine, described in the gas engine section at p. 157, a carburator of the simplest description is added to the ordinary motor. It is a cylindrical vertical reservoir divided horizontally into three parts; the volatile hydrocarbons are stored in the upper, and are thence

supplied to the second chamber below it, which forms the carburator itself. Enough liquid can be carried in this reservoir for an ordinary day's work. The products of combustion from the cylinder are led through the lowest division, warm the carburator, and counteract the cold produced by the evaporation of the hydrocarbon liquid. The Tenting carburator is a good example of the method of carburating air by bringing it in contact with light hydrocarbon, without the application of much heat. Air, drawn in by the out stroke of the piston, is passed over the surface of the liquid in the central chamber. It enters on one side, and is carried off from the other to the cylinder, charged with the volatile petroleum essence.

**Durand.**—In the Durand engine the vaporisation of the oil is effected on a different principle to that usually adopted in petroleum motors. As a rule, the oil is sprayed by dividing it up with the injection of air, and evaporating it by great heat, the aim being, if possible, to convert the whole into vapour, without any residuum. M. Durand uses only the light volatile constituents of the oil, the heavy hydrocarbons are allowed to accumulate at the bottom of the carburator, withdrawn and wasted. He thinks there is a gain in power and smooth working by this method, and these advantages more than compensate for slightly increased consumption of oil. The Durand carburator is fixed above the cylinder, the heat from which counteracts the cold produced by evaporation. By this arrangement the carburetted air descends only, and does not lose its inflammable properties, as it has been found to do when ascending. Air is drawn into the carburator through a vertical tube, the bottom of which is below the level of the hydrocarbon liquid. It rises through a spongy mass on the top of the liquid, always saturated with hydrocarbon. Thus charged, the air is carried off through a pipe to the distributing chamber, where it is further mixed with fresh air to form the charge. The opening of the valve admitting the oil vapour to the chamber is regulated by the governor, according to the speed. Electric ignition is used; contact is interrupted and the spark produced by a rotating disc, worked from the auxiliary shaft (see p. 72).

**Forest.**—M. Forest of Paris has lately turned his attention specially to small marine engines working with petroleum, and in conjunction with M. Gallice has produced several motors, which have attracted the attention of the French Government. One of their engines, of 30 H.P. with six cylinders, bought by the French Admiralty, was tested at Brest in 1890. Details of the trial will be found in the table at p. 404. A carburator on the Pieplu system is used, with light hydrocarbon. The surface of the petroleum is agitated by a rotating cylindrical brush. The air is drawn in by suction, and the petroleum being sprayed into it by the brush, it becomes charged with the evaporated liquid.

The special feature of these Forest motors is that they are reversible, rapidly started, and that the direction of the engine can be instantly changed. The marine motors have two or more vertical cylinders working downwards on the crank shaft. A distributing shaft, from which all the ignition and exhaust valves are driven, runs above the cylinders. This shaft has a double set of cams, one for working the boat forward, the other for reversing the direction, and by slightly shifting the position of the cam to the right or left, one or the other set can be brought into play. The charge is fired electrically, and the spark is produced or missed, according to the movement of the distributing shaft. The arrangements for rapidly changing the direction by reversing the engine depend on the adjustment of this shaft. Drawings of this ingenious motor will be found in Witz. Other French engines working with petroleum are the Mire and the Noël, both shown at the Paris Exhibition of 1889.

**Capitaine.**—Among German motors, the Koerting can be used with petroleum. The Benz is also sometimes driven with carburetted air, and the charge fired by electricity. A more important engine is the vertical Capitaine, described at p. 187. It has already been about four years at work, and was one of the first motors to use common petroleum. It has been introduced into England, and a launch driven by a Capitaine oil engine, fitted with friction cones and bevel gearing, was tested at Chester in December, 1891. By means of a handle attached to the gearing, the motion of the boat could be reversed or suspended. This launch was 35 feet long by 6 feet 10 inches, and carried fifty passengers. The $6\frac{1}{2}$ H.P. engine made 240 revolutions per minute; the boat went at $8\frac{1}{2}$ knots an hour. About twenty-five of these little boats are at work in Hamburg, and many are used in other parts of Germany. The manufacturers state that over 1,000 engines have within twelve months been made for Germany and Russia.

Like the gas engine of the same name, the Capitaine petroleum motor differs in one or two respects from others, and especially in the stratification of the charge. In both engines the same cycle and method of construction have been adhered to. The diameter of the water-jacketed cylinder is larger than in the usual type of motor, and the stroke shorter. The admission ports are so designed that the charge enters at a high pressure, and is rapidly expanded. The compression chamber is conical, and where it joins the cylinder it is of the same diameter. The ignition port is so arranged that part of the charge enters the tube at the moment of ignition, and is fired without a timing valve. In both the gas and oil engines the exhaust valve is worked by an eccentric on the crank shaft, and in the petroleum motor this eccentric also drives the oil pump, which is on the other side of the cylinder. As the four-cycle is used, with an

explosion every second revolution, an alternating mechanism is employed to throw the levers operating the exhaust and oil pumps out of gear, and cause them to miss the valves at every second stroke. The governor is carried on the flywheel, and revolves horizontally. If the speed be too great the governor balls fly out, the bell crank operating the exhaust is caught, and the valve held open, while at the same time the rod working the oil pump is maintained in its highest position. No oil is admitted, and all the valves are at rest until the speed is reduced. Above the ignition tube, at the opposite side of the cylinder to the exhaust, we have in the Capitaine oil engine a vaporiser. The valves D and S (Fig. 93, p. 188) are retained at the top, but they admit air only, to mingle with and dilute the already vaporised charge. The oil enters the suction of the oil pump by gravity; it is then forced upwards by the small piston driven by the eccentric working the exhaust into the vaporiser, which occupies the same position as the ignition tube B, Fig. 93. The vaporiser is a small horizontal iron tube, maintained at a red heat by a lamp below. This lamp is provided with a long bent tube, at the end of which is a conical burner; the flame of the burner not only evaporates the oil in the vaporiser, but in the tube. Being bent, the oil in it is exposed to greater heat from the flame. In the earlier oil engines, the flame also played upon the small ignition tube. Firing by tube has recently been discarded, and the heat of the vaporiser alone is found sufficient to ignite the charge, after its compression by the piston. Unlike the arrangement usually adopted in oil engines, the heat of the exhaust gases is not utilised to vaporise the oil.

On entering the vaporiser, the oil is met by a small current of air, drawn in at the same time, at right angles to the oil, by the down stroke. As the oil pump injects only a minute quantity of oil at each stroke, it is instantly vaporised by the heat, and passes on to the cylinder. The air continues to enter, and thus a cushion of highly inflammable oil vapour is formed next the piston, and behind it probably a cushion of hot air only. At the same time the suction stroke lifts the valves, and air enters through the admission valve at the top of the cylinder (as in Fig. 93); the charge is diluted, the next compression stroke of the piston forces it back into the vaporiser, where it is ignited and fires the charge. These two currents of air are said to form a non-inflammable layer, and to prevent the oil vapour in
from communicating with the red-hot vaporiser, until
stroke of the piston. The air drawn into the vapo
suction of the piston, drives before it the inflamma
into the cylinder. Herr Capitaine maintains th
is employed to vaporise and ignite the charge,
isation and combustion are therefore more comp
the stratification of the oil vapour and air, the

is hotter than the bottom, heat is imparted to the charge during its expansion, and raises the pressure curve. The indicator diagrams are said to confirm this theory. The consumption of oil claimed for the Capitaine engine varies from 1 pint per B.H.P. with 1 H.P. engines, to 0·7 pint per B.H.P. per hour with engines of 4 H.P. and upwards. It is maintained that premature ignition is impossible, and that the engine, on account of the great heat of the vaporiser, and therefore of the charge, works without any deposit of carbon. A drawing of the Capitaine oil engine, with indicator diagrams, will be found in *Engineering*, January 1, 1892.

**Daimler.**—The Daimler petroleum motor differs in some respects from the gas engine of the same name described at p. 178. It has already been successfully employed for driving small boats, and has been fitted in about 480 launches; a 37 feet launch driven by a 10 H.P. Daimler oil motor was recently supplied to the London County Council. The author was lately permitted to inspect one of these little petroleum launches on the Thames. It ran quietly, with no smoke, and no perceptible smell, was easily steered, the direction reversed, or the boat stopped at a moment's notice. The speed varies from 8 to 10 or 11 miles an hour. More than fifty boats equipped with these motors are in use in Hamburg, and they have also been applied for driving fire engines.

As in the gas engine, the Daimler petroleum motor has two single-acting cylinders, the pistons of which are set at an angle of 180°, and work upon the same crank shaft, but they have no valves. Fig. 125 shows the arrangement of the parts. In the oil receiver or vaporiser A (which is previously filled with petroleum), vapours are generated by means of the suction of heated air through the oil. The tube conveying this hot air to the top of the vaporiser is surrounded with a jacket, through which the products of combustion are led on their way to the open air. The oil vapour and air then pass to the regulating valve H, where more air is added to dilute them in proper proportions. They are next conveyed to the cylinder, entering through an automatic lift valve, as in the gas motor. The back stroke of the piston compresses the charge in the usual way. Ignition is effected by means of two small lamps, L, one for each cylinder. These lamps are fed from the receiver B, to which oil is supplied from the reservoir R, and the valve cock *p*. The passage of the oil to the lamp is regulated by means of the valve V, and the lamps burn with a clear blue flame. Within them are fixed two very small platinum tubes *b*, kept at a white heat, which fire the charge in either cylinder automatically, without a timing valve, at the end of the compression stroke. Upon the proper burning of these two little lamps, the efficient working of the engine in great measure depends. The same passage serves

to admit the fresh charge to the cylinder, and to carry off the gases of combustion; the exhaust valve rod is worked from the crank shaft by wheels 2 to 1. The governor on the flywheel checks the admission of the combustible gas, when the normal speed is exceeded. The engine works with petroleum of 0·68 to 0·70 specific gravity, and flashing point under 73° (Abel's test). Great care must therefore be exercised in handling and

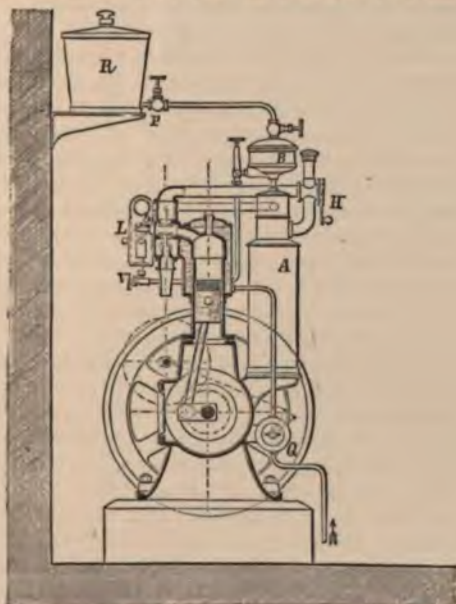


Fig. 125.—Daimler Oil Engine—Section of Cylinder and Valves.

storing the oil. The cost of working is said by the manufacturers to be about 1d. per H.P. per hour. The sides and covers of the cylinders are cooled by water jackets. Drawings and a full description of the Daimler oil motor will be found in *The Engineer*, April 14, 1893.

**Adam.**—The Adam petroleum engine resembles the gas motor of the same name, already described at p. 171, with the addition of a vaporiser. Benzine or naphtha are used to drive this engine, and enter the generator in a liquid state from a receiver. The oil is here converted into gas and passes to the cylinder, part going to form the charge, and part to heat the ignition tube. During the whole process, the benzine is carefully protected from coming in contact with the outer air. The consumption is given at a little over 1 lb. of benzine per H.P. per hour. The engine is made in nine sizes, from ½ to 10 H.P. indicated.

The Berliner Maschinen-Bau Gesellschaft have also brought out a small engine for petroleum.

**Altmann and Küppermann.**—An oil engine made by this firm in Berlin is compact and simple; the method employed for vaporising and igniting the oil is very practical. The engine is vertical, and the piston works upwards on to the crank. Admission, ignition, and exhaust are effected from a small auxiliary shaft, worked from the main shaft by two sets of conical wheels. The petroleum is drawn from the reservoir through a suction valve, and delivered by a small pump with adjustable stroke into the vaporiser, a shallow vessel heated by a spirit lamp below. The lamp is protected by a cover, and the hot ignition tube projects into the flame. A separate receiver, into which air is compressed by an india-rubber valve, feeds the lamp. The vaporised oil then passes to another valve chamber, where it is diluted with air before entering the cylinder. Here it is exploded, and expands in the same way as gas, the usual Beau de Rochas four-cycle of operations being carried out. The oil pump and the suction valve admitting the oil from the reservoir are worked from the same lever. A cam on the auxiliary shaft lifts a roller on the lever once in every two revolutions, if the speed is regular. If the engine is running too quickly, the cam, which is held in position by a spring, is thrown out of gear by a smaller projection, and misses the roller. The lever not being lifted, no oil enters the cylinder until the speed is reduced.

**Lüde-Vulcan.**—A more important petroleum engine, constructed by Langensiepen of Magdeburg, and designed by Herr v. Lüde, has been tested by Professor Schöttler. It is a horizontal four-cycle motor, self-contained, with hot-tube ignition. Although its advantages are somewhat counterbalanced by the many levers, &c., Professor Schöttler is of opinion that it is the arrangement of the parts, not their number, which makes the engine appear complicated. The admission, distribution, and exhaust valves are worked by cams and levers. The exhaust lever is acted upon by a cam on the auxiliary shaft, parallel to the crank shaft, and driven from it by spur wheels; the same shaft works the oil pump and admission valve. The ball governor is fixed upon the crank shaft inside the driving pulley, and acts by cutting out the number of explosions. If the speed be too great, it pushes forward a projection, which catches in the lever of the admission valve; the valve is not raised, and no charge enters the cylinder.

The most original parts of this engine are the methods of conveying the oil to the vaporiser, and the lamp. The oil descends by gravity from a petroleum tank above the cylinder, and passes through the suction valve of the oil pump, worked by the auxiliary shaft, which also regulates the descent of the little plunger piston. The stroke of the pump is always the same, and

delivers an equal quantity of oil, but the pump communicates with two delivery valves and pipes. One opens a passage back to the oil reservoir above. The other has a nozzle attached, through which a certain quantity of oil is injected, at every stroke of the oil pump, into the air valve. Air enters at the same time, the valve being worked by the same lever. The proportions of oil sent on to the vaporiser and motor cylinder, and returned to the reservoir, are determined by the adjustment of a screw in the plunger of the oil pump; the stroke is regulated by moving a handle. The oil being sprayed into the air, the two pass into the vaporising chamber below, communicating with the cylinder. At starting, this chamber is heated by a lamp fed from a second reservoir of petroleum spirit. As soon as the engine is at work, the heat generated by the explosions is sufficient to keep the vaporiser at a suitable temperature; the lamp on its stand is then drawn back a little, and serves to heat an ignition tube of the ordinary type, connected to the vaporiser. The lamp consists of a coil of pipes, in which the petroleum is converted into gas by the heat of the flame; the amount of oil passing into it at a time is regulated by a screw valve, and it is said to burn with very little carbon deposit. The engine runs at a high speed, making in the small $1\frac{1}{2}$ H.P. motors 600 revolutions per minute. In the motor tested by Professor Schöttler, the mean speed was 325 revolutions per minute. The engine indicated 6·7 H.P., and the consumption of petroleum, not including the lamp (which requires $\frac{1}{8}$ pint per hour), was $\frac{3}{4}$ pint per H.P. per hour. The specific gravity of the oil used in the trial was 0·828. Like most engines in which the oil is gasified in a separate vaporiser, the parts have to be lubricated in the ordinary way.

The same engine is made by G. Kühn of Stuttgardt, under the name of the "Vulcan." It was shown at the Frankfort Exhibition of 1891, and the author saw it working well at the high speeds given. The consumption of oil varies, according to the makers, from 1·1 lb. for engines of 1 to 2 H.P., to about $\frac{3}{4}$ lb. in engines of $5\frac{1}{2}$ to $6\frac{1}{2}$ H.P. These two last engines are fully illustrated in *Zeitschrift des Vereines deutscher Ingenieure*, August 29, 1891.

An oil engine has been recently patented by Brunler, of Leipzig, having three cylinders and pistons revolving round the crank. Air, into which a jet of petroleum is injected, is drawn into the cylinders at each stroke; the petroleum is previously vaporised in a separate chamber.

## AMERICAN ENGINES.

**Caldwell.**—The Caldwell-Charter engine,
H. W. Caldwell & Son, Chicago, is intended

either gas or petroleum. In the latter case the oil is drawn from a reservoir in the base, and forced by a small pump, close to and worked from the crank shaft, into a brass pan, where it is mixed with air in the proper proportions. The air is drawn in through two pipes, and the admission regulated by the governor on the crank shaft. The engine works with the ordinary four-cycle, has a water jacket, and ignition by a hot tube heated by a small gazolene burner. A 95 I.H.P. engine is running at Camden, United States.

**Foos.**—Another American engine, working with either gas or light petroleum spirit (gazolene), is made by the Foos Gas Engine Company, Springfield, Ohio. The motor is fired electrically, the connection and separation of the electrodes being effected from the main shaft through gear wheels. No attempt is made to vaporise the oil. It is contained in a tank at the side of the engine, and air, previously warmed by passing round the exhaust valve, is drawn by the suction stroke of the piston through the petroleum vapour, which it absorbs in its passage to the admission chamber. The engine is of the usual four-cycle type.

**Kane.**—Of the same class of motor is the Kane, built by Messrs. Kane, of Chicago. The carburator is simply a small circular tank partly filled with light petroleum spirit, through which air is drawn, and is charged with oil vapour in its passage. No heat is applied to the air or oil. The engine is fitted with reversing gear, and has been specially adapted for marine use.

**Nash.**—An engine working chiefly with gas, and not fitted with any carburating or vaporising apparatus, is the Nash, made by the National Meter Co., New York. As in some other engines already described, the crank is enclosed to form a chamber for compressed air, and the motor resembles the Day in some respects, though not so simple, and has an explosion every revolution. The charge is compressed below the piston, and passed up through a passage in the side of the cylinder to the top, where combustion takes place. Ignition is by a flame, which is made to rotate in a circular chamber.

**Safety.**—The Safety Vapor Engine, made by the Company of that name in New York, is a small vertical gas engine of the usual four-cycle type, which can also be driven with gazolene. It has one noticeable feature. The valve for admitting the charge to the cylinder and expelling the burnt products is a circular rotatory valve, worked by a chain revolving on a pulley of twice the diameter of a smaller pulley on the crank shaft, from which it is driven. Although hitherto made only in sizes from ½ to 6 H.P., the engine is intended for marine use, and has frictional driving gear for connection to the propeller shaft.

**Van Duzen.**—A more important motor, made in several types, stationary and portable, for both gas and petroleum, is built by the Van Duzen Gas and Gazolene Engine Co , of Cin-

cinnati. The engine is horizontal, of the four-cycle type; the admission, ignition, and exhaust valves are worked by rods and cams on an auxiliary shaft below the crank shaft, and revolving at half the speed. This engine is fitted with a carburator, though no heat is used to vaporise the oil. Light petroleum spirit is contained in a chamber at the side of the engine. Air is drawn upwards into a vertical tube below this chamber, and lifts a valve, causing the oil to flow down and mingle with it, as it forces its way through another lift valve, and down the sides of the vertical carburator. The petroleum is vaporised by the force of the air current, as it drops through gauze rings. At the end of the admission stroke the flow of air ceases, the valves fall back on their seats, and the supply of oil is cut off. Hot tube ignition is used, and above the chimney protecting the tube is a ball, which is said to act as a cushion, and disperse the waste products in the ignition tube. This engine is especially adapted for portable motors.

**Sintz.**—The Sintz engine is made in sizes from 1 to 15 H.P. by the Sintz Gas Engine Co., of Grand Rapids, Michigan. It closely resembles the Day; when intended to be driven by oil a small pump is added, which injects a fine spray of light petroleum into the compressed air, as it passes from the enclosed crank chamber to the upper part of the cylinder.

**Hicks.**—The only noticeable feature of the twin-cylinder Hicks gas engine, made at the works of that name, Cleveland, U.S., is that the two cylinders are placed vertically one above the other, and are supported on the same frame. In other respects the engine follows the usual four-cycle series of operations, but having two cylinders, an explosion in one or the other is obtained at every revolution.

**Hartig.**—A small vertical engine, in sizes from ½ to 8 H.P., is made by the Hartig Gas Engine Co., Brooklyn, New York. It is worked with gas only, and does not appear to have been adapted for petroleum. The usual four-cycle is employed. There are four valves—the governor, admission, ignition, and exhaust. The admission of the gas and air is automatic; the other valves are driven by rods, cams, and gear wheels from the crank shaft.

**Trusty.**—The Trusty oil engine has been taken up by Messrs. Connelly, of the Connelly Motor Co., and especially adapted for use on tramways. Several of the Chicago lines are worked with it, and it is largely used in the United States. The engine is the same as that already described at p. 312, but it is fitted with mechanism for varying the contact pressure on the rails, giving the maximum on a curve or when starting the engine, and the minimum when running at full speed. The motor is also made to travel in either direction. The charge is fired electrically. There are two cylinders, and an impulse every revolution is obtained from them alternately. The motor now used (1893) to

either gas or gazolene is the Pacific ...
Engine Co., of San Francisco, and the G...
Philadelphia. It is especially adapted for m...
reversing gear, and has a clutch lever for
the propeller shaft. Water for the cooling
and returned to the water round the boat.
never reversed, but only the direction of m...
and secondary engine shafts. The exhaust
in every two revolutions by a double-groo...
shaft, into which a projection fits, after the
the Daimler engine. The governor acts o...
and holds it open if the normal speed be ex...
isation of the oil is effected as in the Van D...
previously heated by the exhaust gases, is ...
the suction stroke of the motor piston into th...
or metal chamber, above which is a tank con...
leum or gazolene. The current of air lifts a ...
quantity of gazolene flows into the vaporiser, ...
be instantly turned into oil vapour by the ho...
is vertical, and is made with two cylinders for

Union.—In the Union horizontal engine, ...
Company, the charge is also fired electrically, ...
and interrupted between two electric wires by ...
on the ignition and exhaust valve rods. The
employed, and the valves are acted upon by ca...
ary shaft. A weight governor is carried on th...
if the speed is too great, the exhaust valve is ...
the same time the admission valve closed by a ...
stationary engines of this type have hitherto b...

induced to put an end to the monopoly. At that time there were 417 wells, with an annual output of 24,800 tons of oil, and the price of petroleum was £3, 10s. per ton. An excise duty was imposed until 1877, since which date there has been no tax or check upon the development of the petroleum industry. The first oil fountain was "struck" in 1873, and the abundant and continually increasing supply has reduced the price from forty-five kopecks to five kopecks per pood. The number of drilled wells increased from 1 in 1871 to 400 in 1883, and the production of refined oil from 16,400 tons in 1872 to 206,000 tons in 1883. The price of land in the oil district round Baku has also risen enormously, and in 1884 it varied from 10s. to £2 per square sajene = 7 feet square. The specific gravity of the crude oil is about 0·822; it yields 27 per cent. of kerosene or ordinary lighting oil, having a flashing point of 36° C.

Robert Nobel, a Swedish engineer, started his first oil refinery at Baku in 1875, and was soon joined by his brother Ludwig, who assumed the principal direction of affairs. The Nobels were the first to lay down a pipe line, at a cost of £10,000, instead of conveying the oil in carts to the distilleries, and the outlay was covered in the first year. There are now seven pipe lines, two belonging to Nobel Brothers, three to private Russian firms, and two to companies; 161 million gallons of oil are thus conveyed yearly to the refineries. Being foreigners, the Nobels had from the first to struggle with severe competition from the Russian firms, and after laying down their pipe line were next obliged to build their own steamers to receive the oil. The first oil or "cistern steamer" was constructed in the Nobel shipbuilding yard at St. Petersburg, and appeared on the Caspian in 1879. The firm have now a regular fleet of vessels, each holding about 750 tons of kerosene, as well as twelve smaller distributing ships on the Volga. They have also established a system of tank cars on all the Russian railways, and possess twenty-seven oil depôts at various chief towns in Russia. More than fifty-four million gallons are sold by them yearly, and they have over forty wells, one of which yielded, in 1882, 112,000 gallons of crude oil. The following table shows the output and price of petroleum from 1873 (the year after the monopoly was taken off) to 1883:—

| Year. | Output. | Price per Ton at Baku. |
|---|---|---|
| | Tons. | s. d. |
| 1873 (monopoly abolished), | 64,000 | 7 9 |
| 1874, | 78,000 | 6 3 |
| 1875, | 94,000 | 15 6 |
| 1876, | 194,000 | 7 9 |
| 1877 (excise duty taken off), | 242,000 | 12 6 |
| 1878, Nobel Period, | 320,000 | 8 8 |
| 1879, Nobel Period, | 370,000 | 6 3 |
| 1880, Nobel Period, | 420,000 | 3 8 |
| 1881, Nobel Period, | 490,000 | 2 6 |
| 1882, Nobel Period, | 680,000 | 2 6 |
| 1883, Nobel Period, | 800,000 | 2/6 to 6d. & lower. |

# PART III.

## AIR ENGINES.

CONTENTS.—Theory—Cayley—Buckett—Stirling's First Engine—Stirling's Second Engine—Robinson—Ericsson—Wenham—Bailey—Rider—Jenkin's Regenerative Engine—Bénier—Diesel.

**Theory.**—In dealing with oil engines, no mention has been made of the theory of heat motors, and of their theoretical and actual heat efficiencies, &c., because in these respects oil and gas engines are based on the same principles. The effects of an explosion of coal gas with air, or oil vapour with air, when mixed in the cylinder of an engine, are similar, and the temperatures, from which the heat efficiencies are calculated, are the same. When we consider hot air engines, the conditions are different. There is no explosion, and no great rise or fall of temperature. A certain quantity of heat is applied to air, which expands and drives a piston, doing work. No boiler is needed, nor is any cost incurred for gas or oil from a tank, the air as working agent being taken from the surrounding atmosphere. There is no risk of explosion from inflammable gas or oil vapour. No change of physical state in the working agent takes place, and therefore all the heat generated and imparted to the air can, in theory, be utilised in work. The two main sources of waste of heat in gas engines are the cooling water jacket and the exhaust. In a hot-air motor there is no jacket (unless as a refrigerator), and therefore less heat should be dissipated, and more available for work. From these considerations, therefore, it seems as though a hot air engine must be not only better in theory, but more economical in practice, than other forms of heat motor.

Such, however, is not the case. Practically, hot air engines do not give results as satisfactory as might have been expected. Though the first engine of this type was designed in 1807, comparatively few have since been made, and their construction has not been much developed, except for special purposes. The reason for this neglect may probably be found in their low actual efficiency—that is, the amount of heat they turn into work. In theory the whole of the heat furnished to the air being utilised in expansion, a high ratio of efficiency should be obtained.

Practically expansion cannot be continued to the pressure of the atmosphere, and therefore some heat remains in the air, and is wasted at exhaust. The theoretical heat efficiency of an engine depends upon the range of temperature—that is, its highest and lowest working temperatures. But if heat be added to the air up to 900° F., and if the temperature of exhaust is 600° F., only the difference, or 300°, will be spent in expansion, and heat equivalent to 600° will be wasted. As in gas motors, the difficulty consists in utilising the expansive force of the agent, or air. Since expansion cannot be unlimited, only a certain proportion of the heat imparted can be turned to account as work. If it were possible by expansion to reduce the air in a hot air engine to the temperature it had before entering the cylinder, an efficiency of about [illegible] per cent. might, according to Professor Jenkin, be realised. The actual heat efficiency, or percentage of work to total heat received in these engines, is only from 7 to 11 per cent., not very different from that obtained in steam engines. The Stirling engine worked between the temperatures 343° C. and 65° C. The theoretical efficiency, according to the formula at p. 116, was

$$\frac{T_1 - T_2}{T_1}, \text{ or } \frac{343^\circ - 65^\circ}{343^\circ + 273^\circ \text{ abs.}} = \frac{278}{616 \text{ abs.}} = 45 \text{ per cent.}$$

The actual efficiency (see p. 344) was 7 per cent.

**Difficulties of Hot air Engines.**—To increase the efficiency and check the source of waste in these engines—that is, the high temperature of the exhaust—the only method would appear to be to increase the ratio of expansion, and this can only be done by raising the initial compression of the air. But this does not produce any real advantage, because the pressure which is expended must be deducted from the pressure exerted upon the piston. To compress the air before it is admitted to the cylinder requires a certain amount of negative work, or work done *on* the working agent. The further compression is carried the greater the proportion of negative work, and the lower the proportion of positive work, or work done *by* the air. If the air be compressed to 100 lbs., 60 per cent. of the work would be required in theory to obtain this compression. It is also difficult to prevent leakages where high pressures of air are used. To keep all the parts of the engine perfectly air-tight is almost impossible, while to obtain an efficient working pressure it is necessary to use a large body of air. Air is a very bad conductor, and does not absorb heat readily, and it expands in comparison with its bulk much more slowly than steam. In the Ericsson air engine, the pressure was only 8 lbs. per square inch.

Hot air engines are therefore unlikely, and seldom suitable to replace steam or gas. Their special advantages are—1. Ease in working. 2. Absolute safety. For these reasons they are employed for driving fog signals on lighthouses, light-

houses, and in other isolated places, where these advantages outweigh the defects. They are also used for domestic and other purposes, namely, pumping, sawing, printing, driving tools, &c.

**Cayley-Buckett.**—The earliest hot air or caloric engine was introduced by Sir George Cayley in 1807, and patented by him in 1837. The original design has been adopted by Mr. Buckett, and practically the same engine is now made by the Caloric Engine Company. Fig. 126 gives a modified view of the Cayley-Buckett Caloric engine. It consists of two distinct parts, like the boiler and motor cylinder of a steam engine. A is the working

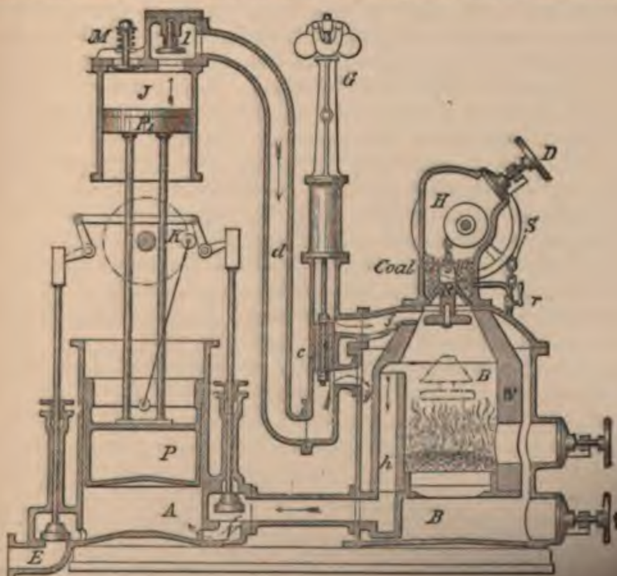


Fig. 126.—Buckett Hot Air Engine—Single Cylinder.

cylinder containing the piston P, B is the furnace in which the air is heated. Above the motor cylinder is a [illegible] cylinder J, into which air is admitted through [illegible] and compressed by the action of the piston $P_1$. Th[illegible] are connected to each other, and the up expansion [illegible] one forms the compression stroke of the other. [illegible] being compressed in J, passes through the valve I [illegible] passage *d* in the direction of the arrows, till it reach[illegible] valve *c*, directly controlled by the governor G [illegible] the current of compressed air is divided. Part of [illegible] the passage *g*, between the fire-brick lining W of [illegible] the outer casing, and is admitted through holes [illegible]

the grate to the furnace B, where it stimulates combustion. The rest passes through the upper part of the valve, enters above the furnace at *f*, as shown by the arrows, and mingling with the products of combustion, prevents the escape of unburnt carbon. From here the hot air and products are carried off through the passage *h* into the motor cylinder, where by expansion they drive up the piston P. They are admitted through a lift valve V which, as well as the exhaust valve E on the opposite side of the cylinder, is driven by valve-rods, levers, and cams from the crank shaft K. Coal is fed into the furnace through the hopper H and the door D. During this time the valve R closes the top, to maintain the air pressure in the furnace during stoking. By opening the cock at *r* a portion of the hot air enters the hopper, and the pressure is equalised. As soon as D is closed, R is lowered into the furnace by the chain *s*. Combustion is regulated by passing more air, either under the furnace at *g*, or over it at *f*. If the speed is too great, the governor acts upon the cylindrical valve, and checks combustion by forcing the greater part of the air to mingle with the products of combustion from the fire. The Cayley-Buckett engine has no regenerator, but by an ingenious arrangement the cold air, after being compressed in J, is led round the valve V, admitting the hot air and gases to the motor cylinder. Thus the valve is kept cool, and the fresh charge of air heated on its way to the furnace. The air being exhausted at each stroke, a closed cycle cannot be obtained.

**Trials.**—In a trial on a 12 H P. nom. double-cylinder vertical Buckett engine, the difficulties of this class of motor were well shown. The gross I.H.P. was 41·24 and the pump I.H.P. 21·04. Thus more than half the power was employed in negative work, leaving only 20·2 H.P. for working the engine. The B.H.P. was 14·39, and mechanical efficiency only 71 per cent. The mean pressure on the pistons was 18·5 lbs., on the pumps 16·78 lbs. per square inch. The coke consumption was 2·54 lbs. per B.H.P. per hour, and only about 8 per cent. of the total heat supplied was turned into work. The engine ran at 61 revolutions per minute, the diameter of the working cylinders was 24 inches, of the pumps 18 inches, stroke 16 inches. Fig. 127 gives an indicator diagram of the engine. A motor similar to the Cayley-Buckett was described with illustrations in *Engineering* in 1887.

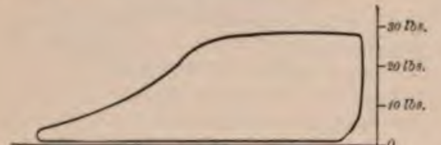

Fig. 127.—Buckett Hot Air Engine—Indicator Diagram.

**Stirling.**—The first application of the principle of the regenerator to heat engines is due to Robert Stirling, a Scotch

minister, who, with his brother James Stirling, an engineer, took out several patents for heat motors, the first dating from 1827. Stirling's double merits as an inventor have not until lately received sufficient recognition from scientific men, perhaps because he was, like many other pioneers, in advance of his time. He first endeavoured to carry into practice the principle of a perfect heat engine (Carnot's cycle), and he also designed the regenerator. In a perfect heat motor the same quantity of heat is imparted to and withdrawn from the working agent, so that at the close of the cycle it returns to its original state, and the series of operations may be reversed. Robert Stirling obtained this perfect theoretical cycle by means of the second great improvement he introduced, the use of a regenerator, in which the heat of the working agent (air) is stored as it leaves the cylinder, and refunded afterwards, as it returns to the furnace. Many scientific men are of opinion that the proper development of the principle of the regenerator affords the chief possibility of improving the working cycle of heat motors. The regenerator has been ingeniously called a "filter," because both the hot and cold charge are "filtered," or passed through it at their highest and lowest temperatures. It is intended to diminish as far as possible the waste of heat at exhaust. It acts by arresting and storing the heat remaining in the working fluid after expansion, instead of allowing it to escape to the atmosphere, and gives back this heat to the next charge in its passage to the cylinder. The result is obtained in this case by making the hot gases pass through thin metal plates, wire gauze, or other heat-absorbing substances, to which they give up their heat, and carrying the cold charge back through the same metal to receive heat from it.

**Stirling's First Engine.**—Stirling took out two patents for hot air engines working with a regenerator. In the first, dated 1827, he proposed to have a motor cylinder and piston, an air pump and two hot air vessels. The vertical motor cylinder and air pump were attached to a horizontal beam driving the crank; an eccentric and parallel motion worked the pistons of the air vessels through a balance beam. Each of these air vessels or cylinders contained a plunger piston composed of thin metal plates forming the regenerator. A furnace being lighted beneath the cylinders, air, compressed by the air pump into a receiver in the base, was admitted at the bottom to start [illegible] engine, and to supply the loss by leakage. By its expan[illegible] drove up [illegible] motor piston, and in its passage through [illegible] gave [illegible] its heat to the regenerator. The cylin[illegible] of the [illegible] were kept cold, and the air on [illegible]mediately chilled. The hot air cyl[illegible] with the bottom, the other with [illegible] As the air decreased in temp[illegible]

piston and the piston of one of the air vessels descended. At the same time the air in the other cylinder being heated expanded, and by its pressure drove down the piston of the motor cylinder. Each time the cold air descended, it passed through the regenerator, and became heated afresh.

In Fig. 128 a modified view of this engine is shown. A is the motor cylinder and P the piston, B the air or displacer cylinder, and D a plunger piston working in it, F the space where the air is heated by the fire. The plunger or displacer D is filled with brick-dust, or other non-combustible material. The circular regenerator R is round D, and consists of metal plates about

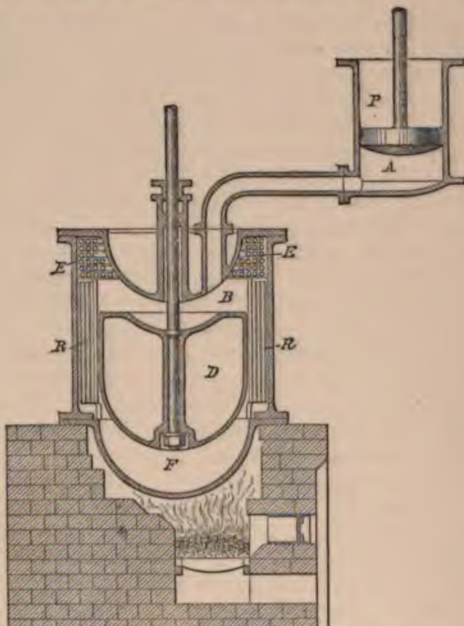


Fig. 128.—First Stirling Engine.

$\frac{1}{40}$ inch in thickness and $\frac{1}{50}$ inch apart. E is the refrigerator at the top of cylinder B, and is formed of coils of copper tubes through which cold water circulates; the hot air from the displacer cylinder acts on the motor piston. The cycle of the engine is as follows:—When the displacer piston is at the top of cylinder B, all the air is below it in F, heated by contact with the fire. As the air expands, its pressure is transmitted to the working cylinder, and it drives up the piston P. The displacer piston is now driven down, and forces the air below, through the regenerator, into the vessel and refrigerator at the top of

cylinder B. While the displacer is in its lowest position, the motor piston comes down. The air in B, which has already deposited the greater part of its heat in the regenerator, is further compressed, and passes around the refrigerator pipes E, where it is cooled, the heat from the furnace being shut out by the non-conducting material in D. By the energy of motion left in the flywheel, D is lifted, and beginning to rise forces down the cold air above it through the regenerator, where heat is added to it before it reaches the furnace. The motor piston P is driven up by its expansion, and the cycle recommences.

**Stirling's Second Engine.**—In Stirling's second engine, introduced in 1840, Patent No. 8652, the regenerator and refrigerator are placed on one side of the cylinder. Fig. 129 shows the arrangement, the parts are lettered as before. C is the displacer cylinder, D the plunger, F the space below it, A the passage leading to the motor cylinder. E is the refrigerator cooled by water, I the passage to the regenerator. The action of the engine is the same as before. There are one motor and two hot air cylinders. The air is delivered into the cylinder by a small pump at a pressure of 150 lbs. per square inch, and passes through the regenerators from one hot air cylinder to the other, driving the motor piston up and down in its passage. There is no exhaust, the same air being used continuously, and a closed cycle is thus obtained. This engine presents in a compact form the main principles of Stirling's invention, and illustrates better than any other type of motor the construction of a perfect heat engine. Here we have [illegible] (the furnace), the source of cooling (the refrig[illegible]

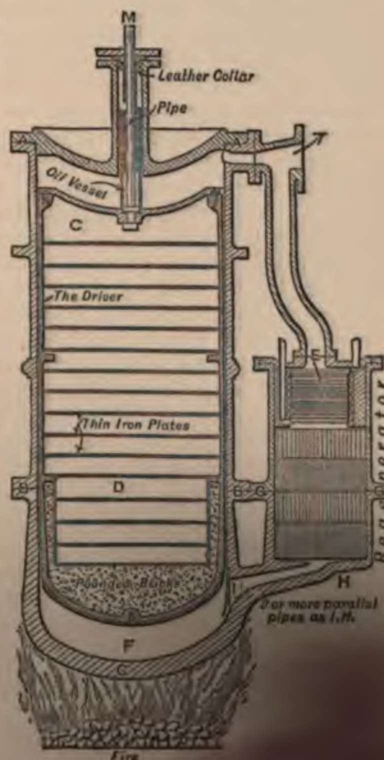


Fig. 129.—Secon[illegible]

heat engine was the result, but in practice it did and only about 7 per cent. of the total heat utilised as motive power. A Stirling engine was machinery for three years at the Dundee Foundry 40 H.P., had a cylinder diameter of 16 inches, an and required about 2¼ lbs. coal per H.P. per hour.

**Robinson.**—A small engine embodying Stirli has been brought out by Robinson, and made by & Co. of Manchester. It is very compact, with single-acting cylinder containing two pistons. Th displacer and regenerator, and is filled with wire in the same way as in the Stirling engine. The cylinder in which the displacer moves to and fro fire-brick, to retain the heat. In the upper par cylinder is the working piston, and here the cy rounded by a water jacket, to serve as a refrigera pistons work through connecting-rods on two diffe right angles to each other; the crank of the d advance of the motor crank, and the displacer-rod a stuffing box in the motor piston. Instead of a g in which much heat is dissipated, the temperature ing agent is raised by a Bunsen burner, fed with passing through a jacket outside the chimney ca products of combustion. When the displacer pis top of its stroke, all the air below it is heated b expands, and drives up the motor piston. As comes down, it forces the air to pass through th into the space above, between the two pistons. So has already been carried off by the regenerator, a further cooled by contact with the cold water refrigerator. The pressure falls, and the working pi

5 inches. A drawing of this engine is given in Professor Jenkin's valuable paper on "Gas and Caloric Engines" (*Proceedings of the Institution of Civil Engineers*, 1883), from which many details of this and other hot air engines have been taken.

One chief reason for the low pressures and small amount of work obtained from the Stirling, and its failure as a practical engine, was that the air was not brought into direct contact with the heat of the furnace. In the displacer cylinder, a thin metal plate intervened between the fire and the hot air, the bottom of which was soon burnt by the great heat. There is no exhaust in engines of this type, the air being used over and over again, and the pump only replacing loss by leakage, but this advantage is counterbalanced by the difficulty of heating the air. In the Cayley-Buckett engine it is passed through the furnace and, mingled with the products of combustion, drives up the motor piston, and is exhausted after expansion, as in an ordinary heat engine.

**Ericsson.**—The latter type of motor is best exemplified in the celebrated engine produced by Ericsson in 1826. As an engineer, Ericsson was a genius not inferior to Robert Stirling. During the first half of this century he introduced numerous mechanical inventions, and is said to have designed the first screw propeller. In his engine hot air was used in conjunction with steam. It was drawn into a furnace below a steam boiler, and after producing combustion of the fuel, and evaporating the water, it was carried off, together with the products of combustion, and drove up the piston of an air cylinder by its expansion. On its way it passed through a regenerator. In an alternative engine described in the same patent, it was proposed to mix the products of combustion and the hot air with the steam, and admit them alternately at either end of the motor cylinder, as in an ordinary double-acting engine. After expansion, they were exhausted into the atmosphere. Thus the heat was applied directly to the air. Of course it was impossible to use the air over again, since it was required fresh at every stroke, to support combustion.

These two engines, the Stirling and the Ericsson, form two distinct classes, into one or the other of which all hot air engines can be divided. In the first, the air does not come in contact with the flame, but is heated by conduction and by the regenerator, and is not discharged at each stroke. In the second, it is applied directly to feed the flame, and, mingled with the products of combustion, produces motive power by expansion, after which it is exhausted. In both engines the practical heat efficiency, as compared with the theoretical, is very low. Admirable as types, they cannot, for the amount of heat they turn into work, be ranked with gas, oil, or steam engines. The chief reasons for this deficient utilisation of heat have been already explained. A large quantity of heat must be added to the air,

before its temperature is high enough to produce a proper working pressure. This necessitates large cylinders, that a sufficient volume of air may be heated, and their bulk, weight, and friction are serious drawbacks to the extended use of heat motors of this type. In a Stirling 37 H.P. engine, the maximum temperature was only 650° F., and the weight 1 ton per I.H.P. The consumption of coal per effective H.P. is also very great, especially in engines of the Ericsson type. The 600 H.P. engine originally made by Ericsson was said to consume 6½ lbs. coal per H.P. per hour, the heating surface of the regenerator was 4,900 square feet. Another of ¾ H.P. was used for thirty years by the Trinity House authorities on board a lightship, and for driving a fog signal was found to give good results. In the Ericsson engine tested by Professor Norton, the I.H.P. was 321, and consumption of anthracite 1·8 lb. per I.H.P. per hour, but there were four motor cylinders, each nearly 14 feet in diameter. These two air motors form the standard types, followed more or less closely by all other hot air engines.

**Wenham.**—The Wenham engine, introduced about 1873, is in some respects similar to the Buckett. The motor is of the Ericsson type, and the air is heated by forcing it through a furnace lined with fire-brick, after which it passes to the vertical water-jacketed motor cylinder, driving up the piston by expansion. The distinctive feature of the engine is that the upper surface of the motor piston is used as an air pump. Air is admitted into the top of the cylinder through an automatic lift valve, when the piston is in its lowest position, and the pressure has consequently fallen. As the piston rises, forced up by the expansion of the heated air from below, the pressure closes the valve, and as soon as the air is compressed to 15 lbs., it forces open another lift valve, and passes to the furnace at the side. In the passage through which it is led off is a valve, connected to the centrifugal governor. Here the current of compressed air is separated, part passing over and part beneath the fire grate, to stimulate combustion. The governor regulates the proportions of the two, and thus the rate of combustion, and the pressure of the air delivered to the motor cylinder. Ordinary coal is burnt as fuel. The hot air, after passing upwards, is led off, mingled with the products of combustion, and admitted to the bottom of the motor cylinder through a lift valve, worked by a cam on the main shaft. A similar cam operates a second lift valve for the exhaust. The admission and discharge ports are both at the bottom of the cylinder. The engine is single-acting, the expansion of the hot air drives up the piston, it descends by the motion of the fly-wheel, and by the pressure of the air stored above it, and drives out the burnt products. There are two piston-rods, both working on to the same crank shaft. The consumption is said to be

as much as 8 lbs. of coal per H.P. per hour, which is probably the reason why these engines have not hitherto been much used. A description with drawings will be found in *Proc. Inst. Mech. Engs.*, 1873.

**Bailey.**—The Bailey engine, shown at Fig. 130, is constructed on the Stirling principle. The products of combustion pass from the furnace to the displacer and power cylinder, where they mingle with and heat the air, driving the piston. The cylinder is horizontal, but in most respects, and especially in the arrangement of the regenerator, the Bailey resembles the vertical Robinson engine. There is one long cylinder, $A_1$, the crank end of which, closed by the piston, is surrounded by a water jacket, and acts as a refrigerator. The other end serves as the heater and regenerator. This cylinder contains two pistons—P the motor, working on to the crank by a connecting-rod, *c*, and series of levers, and $P_1$ the long displacer, the connecting-rod of which

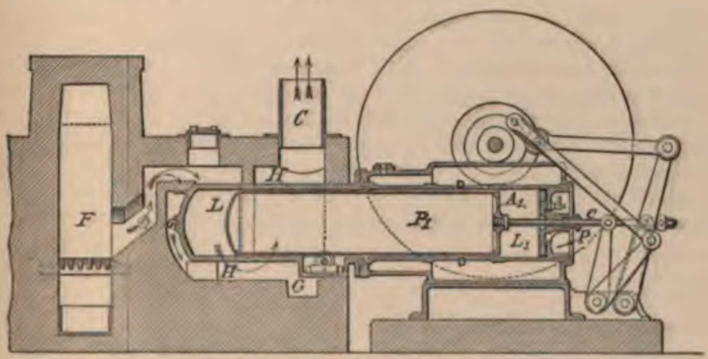


Fig. 130.—Bailey Hot Air Engine.

passes through the motor piston, and works on to a separate crank at right angles to the main crank. The displacer $P_1$ does not fit closely into the cylinder $A_1$, but a small passage is left between them, shown at D. This piston is used merely to cause the air to travel backwards and forwards in the cylinder; all the work, including that of driving the displacer, is done by the motor piston. At H is a steel casing enclosing the inner end of the cylinder; F is the furnace. The hot gases and products of combustion pass upwards from the furnace over the fire bridge, in the direction of the arrows, into the space G round H, and the burnt products are carried off through the flue C. The air enclosed in the space L becomes highly heated, and drives out the displacer. As it reaches the narrow opening D, it is chilled by the water jacket, and before it has passed into $L_1$ on the other side of the displacer piston $P_1$, it has parted with all its

heat. As the air cools its pressure is reduced, the working piston and displacer make their return stroke, and the cold air is drawn back into the space L, to be reheated first by the steel casing, then by the furnace gases. Thus the heat is added when the temperature of the air has already been raised by the hot end of the cylinder, and withdrawn by the refrigerator after it has been cooled by expansion.

The Bailey engine is said to be based on the designs of MM. Lehmann & Laubereau, but it is really an English engine, strictly modelled on the Stirling type, though the idea of a regenerator is not much developed. There is no exhaust for the hot air, which is used continuously, and the loss by leakage is replaced from time to time through a small valve, when the pressure falls below atmosphere. The absence of valves is an advantage in this class of engine, because the great heat necessary to obtain a working pressure soon wears them out, and causes them to become loose. As the air is introduced direct from the surrounding atmosphere, and no compression pump is used, the maximum pressures are very low. The following details of a trial from Professor Jenkin's paper on "Gas and Caloric Engines" gives the working of a Bailey hot air engine:—The speed was 106 revolutions per minute, and the engine indicated 2·37 H.P.; the mechanical efficiency was 55 per cent., the brake H.P. being 1·31. The stroke was $6\frac{7}{8}$ inches, diameter of cylinder $14\frac{5}{8}$ inches. The highest pressure obtained was 14·7 lbs. per square inch above atmosphere, and the temperature at this pressure was 823° C. The consumption of coal was said to be under 10 lbs. per hour. Fig. 131 gives an indicator diagram taken during this trial. The engine works easily and steadily, and requires scarcely any attendance. Messrs. Bailey make 7 sizes, from $\frac{1}{4}$ to $3\frac{1}{2}$ H.P., at speeds from 120 to 80 revolutions per minute.

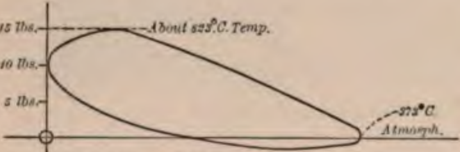

Fig. 131.—Bailey Hot Air Engine—Indicator Diagram.

The figures of the trial show that to obtain a pressure of only one atmosphere, a relatively high consumption of coal and high temperature are necessary. These are partly owing to the transmission of the heat through metal to the air. But the difficulty is not removed by passing the air directly over the fire, as in the Ericsson engine, and driving the piston by the expansion of the hot furnace gases. Since the air must be discharged at every stroke, fresh air is continually introduced, and much of the heat obtained is wasted at exhaust. It has also been found that the air, in its passage through the furnace, becomes charged with grit

and unburnt carbon, which score the valves and passages, and cause friction and wear of the working parts.

**Rider.**—The Rider is an ingenious little hot air engine brought out in America, and made in this country by Messrs. Hayward & Tyler. It is a compact and handy single-acting motor, and is used for domestic purposes, and to pump water. It presents almost all the features of the Stirling type, the regenerator, the furnace below heating the air through metallic walls, with no exhaust or other valves. There are two vertical cylinders, as shown at Fig. 132; one is heated by the furnace beneath, the other is kept cool by a water jacket. The same air is used continuously, and is passed alternately from one cylinder to the other. Unlike the Stirling, however, the motor piston is placed in the hot cylinder of this engine, and it is here that the power is developed. A is the working, and B the second cylinder, which acts as compressor, displacer, and refrigerator. Each has a plunger piston of unequal stroke and diameter, P and $P_1$, working through connecting-rods, J and $J_1$, on two cranks on the main shaft, carrying the flywheel. The cranks are set nearly at right angles. The cylinders are open at the top, closed only by the pistons. W is the water jacket surrounding the compression cylinder B; the piston of cylinder A ends in a concave cylindrical part, F, over the furnace, round which the hot air circulates. Between the cylinders is a passage containing the regenerator R, formed of a number of very thin iron plates. As the air passes through this regenerator it either takes in or gives out heat, according to the direction in which it is going, whether from the hot to the cold cylinder, or back again. The fire at G greatly heats the air in the space above it at F, and forces up the piston P by expansion. Meanwhile the displacer $P_1$ is at the bottom of its stroke, it then begins to rise slowly, drawing over into cylinder B, by its suction, part of the hot air in A. Until this air is completely cooled, its pressure helps the ascent of piston $P_1$. When the motor piston P has reached the top of its stroke, the other plunger is more than half way through, and as P descends, it displaces all the hot air in cylinder A, and drives it into the cold cylinder B, through the passage and regenerator R, where a large portion of its heat is deposited. The air, already reduced in temperature, is further cooled by the water jacket W, its pressure falls, and the plunger piston $P_1$ descends, compressing the cold air below it. It is during this period—the last part of the down stroke of $P_1$—that the flywheel does work, there being no air in the hot cylinder to act by expansion, but the power exerted during this compression stroke is not nearly as great, as the power previously developed by the expansion stroke in A. By the time the plunger $P_1$ has reached the end of its stroke, the motor piston has begun to rise, and the air is again displaced and transferred from the cold to the hot cylinder. As it passes back, it absorbs

heat from the regenerator, and more heat from the concave part F in the motor piston, which forces it against the hot walls of A. When it reaches the furnace the cycle recommences.

The chief peculiarity of the Rider engine is that the motive power is not only generated but exerted in the hot cylinder,

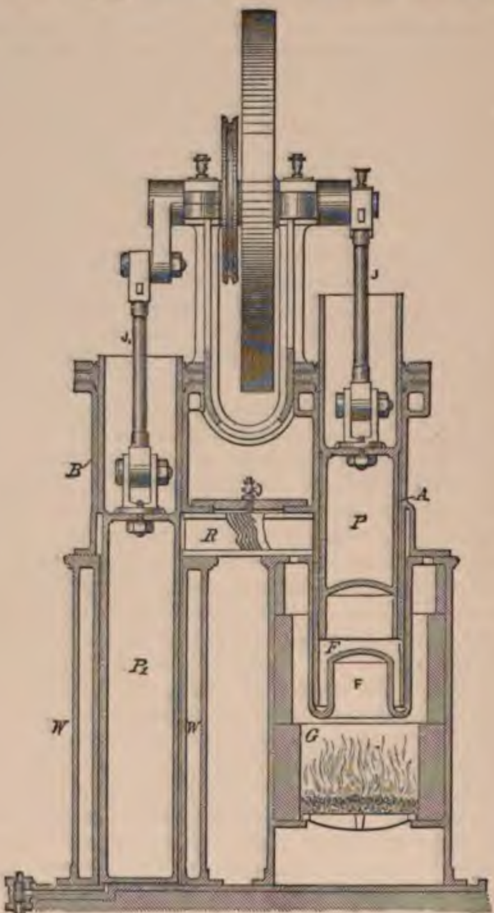


Fig. 132.—Rider Hot Air Engine.

above the furnace. This is not a desirable arrangement. In all his various designs, Stirling was careful to keep the motor cylinder cool, and even in the modifications of his engine where all the operations take place in one cylinder, that part of it containing

the working piston is cooled by a water jacket. The Rider engine is mostly made in sizes from 1 H.P. and less. The speed is from 100 to 140 revolutions per minute, and the maximum pressure about 20 lbs. above atmosphere. The consumption of coke varies in $\frac{1}{4}$ and $\frac{1}{2}$ H.P. engines from 25 lbs. to 18 lbs. per B.H.P. per hour.

**Jenkin's Regenerative Engine.**—A hot air engine on the Stirling principle, with a regenerator, but in which hot air passes directly over the furnace and, mingled with the products of combustion, drives up the piston, was introduced by Fleeming Jenkin. In the first type of his Fuel Regenerative engine, patented in 1874, coal gas and hot air were used together to form an explosive charge. This vertical engine had a combustion cylinder with displacer piston, a motor cylinder with working piston, and two pumps for compressing the air and gas, all driven from the same crank shaft. The combustion cylinder is lined with fire-brick, and has below it a chamber formed by the clearance space, and continually maintained at a white heat by the explosions of compressed gas and hot air taking place in it. The displacer piston contains the regenerator of fine wire gauze, as in the Stirling engine; at the top of this cylinder is the cooling chamber. The air from the air pump is driven into the upper part, and forced downwards through the regenerator by the displacer piston as it rises. In the combustion chamber it mingles with the coal gas or petroleum admitted into the cylinder by a second pump, and the compressed air, already heated by its passage through the regenerator, produces the ignition of the charge. The hot gases and products of combustion expand, and, entering the bottom of the motor cylinder at a high pressure, force up the piston. The exhaust gases are passed through the regenerator before being allowed to escape into the atmosphere. A drawing of this engine will be found in Robinson.

A second regenerator engine, designed by Professor Jenkin and Mr. Jameson was described, with drawings, in Professor Jenkin's paper already referred to. Here the object was to construct an engine of the Stirling type, but in which the heat was directly transmitted to the motor piston. One cylinder only was used, the upper part containing the refrigerator, and the lower the regenerator. To keep in the heat, it was found necessary to line, not only the clearance space, but the cylinder itself outside the regenerator with non-conducting refractory material. Great difficulty was experienced in dealing with this substance, owing to its porosity. The inventors were finally obliged to use a fire-brick lining of great thickness, and a separator or metal plate, dividing it into two parts. Even with these precautions the clearance space was much too large, and there was consequently great loss of pressure. To work the engine a coke fire was made below the cylinder, and the air as it became heated drove up the pump or displacer. As it expanded, it passed

through the regenerator round the circumference of the cylinder. Here heat was withdrawn from it, and it became still further cooled by contact with the refrigerator or water jacket, at the top of the cylinder. The contraction of the cold air caused it to pass downwards again to the fire, and heat was restored from the regenerator, and from the fire-brick lining of the clearance space. This engine did not go beyond the experimental stage.

**Bénier.**—MM. Bénier, whose gas engine is mentioned at p. 70, brought out in 1886 a hot air motor, which appears to have met with considerable success. It is a vertical single-acting engine; the piston-rod works through a horizontal beam on to the connecting-rod and crank. Fig. 133 gives an external view.

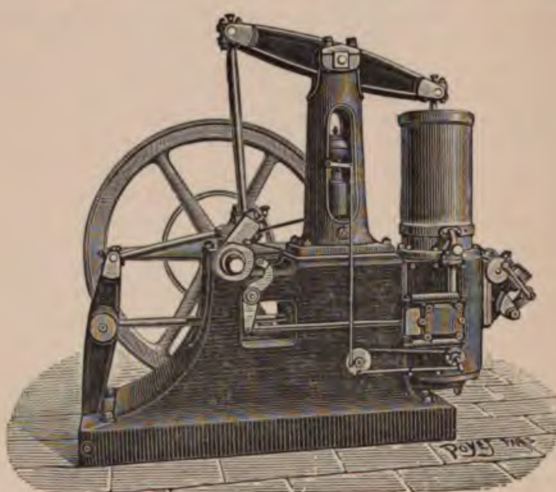

Fig. 133.—Bénier Hot Air Engine.

There is one motor piston, with furnace below; the connecting rod and crank shaft are shown to the left in the drawing. Another rod works the horizontal air pump, seen through the opening in the base of the engine, by means of a rocking lever. The air pump is single-acting, and sends a current of air at each stroke to the furnace below the cylinder through a slide valve. The valve works between a slide face and cover, and has openings corresponding to ports in the cylinder. It is driven by a cam on the crank shaft actuating a lever, and is held in position by springs. The centrifugal governor inside the central column is worked by a pulley on the crank shaft. It acts through a small lever, a series of rods, and a disc, upon a small crank below the air pump, and closes the air opening from

the pump to the furnace more or less according to the speed. A spring maintains the disc and crank in position. The air is drawn cold into the air pump, and delivered at a pressure of 15 lbs. per square inch into the furnace, where it expands and acts directly upon the piston, as in engines of the Ericsson type. The greater part passes downwards to the grate, but part is ingeniously introduced into a small groove hollowed out in the cylinder. The motor piston is very long, and the lower part is made slightly smaller than the cylinder, and does not exactly fit it. In the space thus formed round the lower end of the working piston, the current of cold air circulates, keeps the piston cool, and prevents the escape of dust or unburnt carbon from the furnace below. The exhaust is on the other side of the cylinder. The products of combustion are discharged through an ordinary lift valve, raised as the motor piston begins to descend, by levers acted on by a cam on the crank shaft. The furnace is fed automatically by means of two hoppers. The proper quantity of small coke for each charge is conveyed from one to the other, and the second hopper, shown to the right in the drawing, discharges its contents into a port in a slide valve which, in its onward motion, shoots the coke down into the furnace. This distributing slide valve is driven by wheels from the crank shaft, and holds the grate hermetically sealed during expansion and the ascent of the piston.

The Bénier appears to be one of the simplest and most efficient of the hot air motors, and requires no attention beyond cleaning out the grate once a day. For coast fog signals it has been tested and approved by the Trinity House Authorities, and is much used in France. Although it works without a regenerator, it gives fairly economical results. A 7 H.P. engine was shown at the Paris Exhibition of 1889, in which the consumption of coke was about 2 lbs. per H.P. per hour. In a 6 H.P. engine the average consumption, with varying loads, was 3 lbs. coke per H.P. per hour. A complete and careful test on a 4 H.P. nominal engine was made by Professor Slaby at Cologne in December, 1887. The speed of the engine was 117 revolutions per minute. The total indicated work in the motor cylinder was 9·23 H.P., pump 3·38 H.P.; available power only 5·85 H.P. The B.H.P. was 4·03, and mechanical efficiency 69 per cent. The consumption of coke was 3·6 lbs. per B.H.P. and 3·1 lbs. per I.H.P. per hour. All the items of heat expenditure were carefully noted, and it was found that only 6 per cent. of the total heat supplied was transformed into useful work. The makers give the consumption of coke at from 3·3 lbs. to 3·9 lbs. per H.P. per hour. The engine is made by the "Société ...çaise des Moteurs à Air Chaud," in sizes of 4, 6, 9, 12, ...H.P. Some of these hot air engines are working in

**Diesel.**—A new motor has lately been patented in Germany, England, and other countries, by Herr Diesel, of Berlin. It is still in the experimental stage, but the inventor hopes to obtain a very much greater economy of heat than has hitherto been reached. It is a single cylinder, vertical, single-acting engine, without a water jacket, employing the Beau de Rochas four-cycle, and designed to run at a speed of 300 revolutions per minute. The principle of the engine is as follows :—Air is compressed in the motor cylinder by the up stroke of the piston to a pressure of from 90 to 200 atmospheres, equal to about 800° to 1000° C. Into this highly compressed and heated air a small quantity of finely-powdered coal, gas, or oil is introduced at the dead point; spontaneous ignition of the inflammable mixture immediately takes place, and the piston is driven down. The inventor claims to utilise about 35 per cent. of the actual heat supplied in useful work, and experiments are now being made with a medium sized motor in Germany. A full description of the new theory of combustion on which this engine is based, will be found in Herr Diesel's new work, *Theorie and Konstruktion eines Rationellen Wärmemotors.* Julius Springer. Berlin, 1893.

# APPENDIX.

## SECTION A.

### PROFESSOR CAPPER'S GAS ENGINE TEST.

*December*, 1892.

The author has been kindly permitted to publish the following experiment made on a 7 H.P. nom. Crossley-Otto engine, at which he was present.

The trial was carried out at the King's College Engineering Laboratory by Professor Capper. Annexed is his report:—

A series of trials has lately been carried out in my laboratory with a 7 N.H.P. Otto gas engine, constructed on the Beau de Rochas cycle by Messrs. Crossley Brothers, and in one which I made on the 7th December, 1892, interesting particulars were obtained as to the composition of exhaust gases, and the transmission of heat through the cylinder walls.

The engine was built in December, 1891, and completely fitted up for experimental purposes. Ignition is accomplished by a red-hot tube and timing valve, as described in the report on the Society of Arts trials, and the pendulum governor acts upon the admission valve, cutting off the gas supply when the speed becomes too great. At full power there is an explosion every two revolutions. The diameter of the cylinder is 8·5 inches, and the stroke 18 inches. The trial on 7th December lasted for two hours, the brake horse-power being 11·33, and the revolutions 162·5 per minute. With 71·2 explosions per minute, about three-quarters of the maximum power was thus developed. The principal observations were taken every five minutes, and it was intended to take indicator diagrams at similar intervals, but this was found impossible, owing to the necessity of changing indicator springs when diagrams for the pumping stroke were obtained. There were thus nine diagrams taken each hour with a Crosby indicator and $\frac{1}{160}$ spring (160 lbs. = 1 inch). For the pumping stroke a second Crosby indicator was used, with $\frac{1}{20}$ spring, and both gave reliable diagrams. A copy of the pumping stroke diagram is given at Fig. 134.

In the accompanying tables, the averages for each hour and for the whole

Fig. 134.

period of two hours are given, and also copies of the indicator diagram nearest to the mean. For the purpose of calculation, a mean diagram, the ordinates of which are the mean of the corresponding ordinates of all the

diagrams taken during the trial, has been constructed (shown by line, Fig. 135), and the expansion and compression lines (dottec been assumed.

The expansion curve (dotted) corresponds to the equation $p \times$ · constant, and the compression curve (dotted), $p \times v^{1\cdot 32} =$ constai will be seen that they both very closely approximate to the actual cu the mean diagrams.

The net work done with the ideal diagram A,B,C,D,E (see Fig.

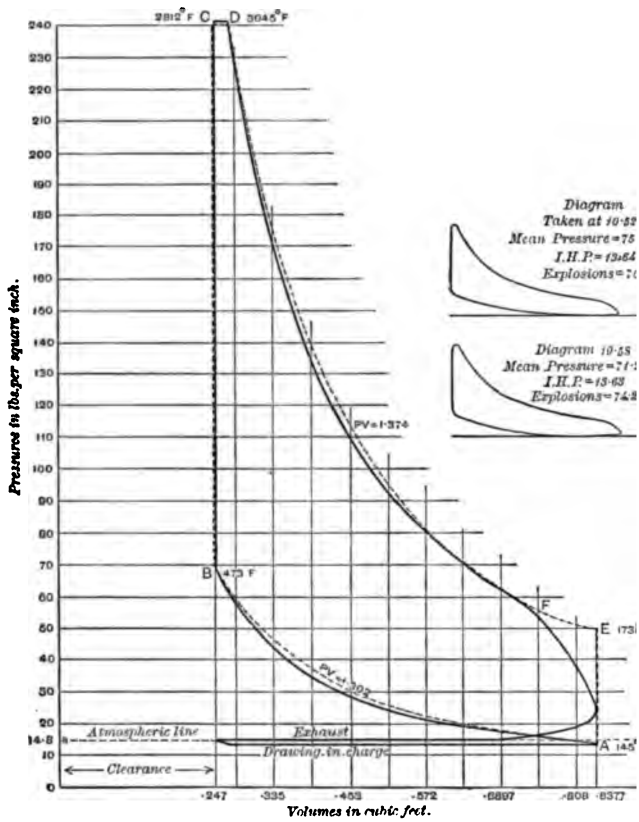


Fig. 135.

6,594 ft.-lbs. per stroke, as compared with 6,345 ft.-lbs. from the indicator diagram.

**Indicated Horse-Power.**—The mean pressure was 74·56 lbs. duri working stroke, and the corresponding indicated horse-power is Allowing for the work expended during the pumping stroke, whic responds to a mean pressure on the piston of 2 lbs. per sq. in., t indicated horse-power was 13·32.

**Brake Horse-Power.**—For absorbing the power, the flywheel was fitted with the usual rope brake, having a weight at one end and a spring balance at the other. A double rope was wound once completely round the circumference of the wheel, and the two portions were kept apart by wooden distance pieces attached to the rope. A little paraffin oil was used occasionally as a lubricant for keeping the wheel cool, and the whole worked very steadily, there being very little fluctuation on the reading of the spring balance. The brake horse-power was, as already stated, 11·33, and corresponds to a mechanical efficiency of $\frac{11 \cdot 33}{13 \cdot 32} = 85 \cdot 06$ per cent. In other words, the B.H.P. was equal to 85 per cent. of the I.H.P.

**Gas Consumed.**—The gas was measured through a 100-light standard meter, made by Messrs. Alex. Wright & Co. The same meter was employed at the Newcastle and Society of Arts trials.

**I.H.P. to drive Engine alone.**—This is the difference between the B.H.P. and the I.H.P., and at 162·5 revolutions = 1·99 H.P.

**Jacket Water for Cooling the Cylinder.**—This was measured by running water through the jacket to waste from two tanks, previously very carefully calibrated. Readings were taken every five minutes on gauge glasses fitted with graduated scales.

**Calculations for Air used.**—The quantity was not actually measured, but has been determined by the following indirect method:—

The meter temperature being 57°·6 F. and the pressure (1·68 inches of water above atmosphere) = 14·86 lbs. per sq. inch, the specific volume of the gas under these conditions would be—

$$\frac{144 \cdot 1 \times (57^\circ \cdot 6 \text{ F.} + 460^\circ \text{ abs.})}{14 \cdot 86 \times 144} = 34 \cdot 87 \text{ cub. ft. per lb.}$$

(144·1 = the constant = the difference in ft.-lbs. between the specific heat at constant pressure ($K_p$) and the specific heat at constant volume ($K_v$) for London coal gas.)

279·75 cub. ft. were passed through the meter per hour, equal to $\frac{279 \cdot 75 \text{ cub. ft.}}{60 \text{ min.} \times 71 \cdot 2 \text{ exp.}} = 0 \cdot 06544$ cub. ft. per explosion.

$$\frac{\cdot 06544}{34 \cdot 87} = \cdot 001877 \text{ lb. per explosion.}$$

Assuming that its temperature after admission to the cylinder is = 145° F., or rather higher than the exit temperature of the jacket water (see Table III.), and that its pressure, as shown by the pumping diagrams, was 13·8 lbs. per sq. inch, the gas would then have a specific volume

$$\frac{144 \cdot 1 \times (145^\circ + 460^\circ)}{13 \cdot 8 \text{ lbs.} \times 144} = 43 \cdot 81 \text{ cub. ft. per lb.}$$

and would occupy a total volume = ·001877 lb. × 43·81
= ·0822 cub. ft.

The volume of the cylinder + clearance is as follows:—

·591 cub. ft. + ·2467 cub. ft. = [illegible] cub. ft.;

the volume occupied by the air

= ·8377 cub. ft. − [illegible] ft.,

and its specific volume under the same conditions of temperature and pressure—

$$= \frac{53{\cdot}35 \times 605^\circ \text{ abs.}}{13{\cdot}8 \text{ lbs.} \times 144} = 16{\cdot}25 \text{ cub. ft. per lb.}$$

[53·35 is difference in ft.-lbs. between specific heat at constant volume, $K_v$ 130·20, and specific heat at constant pressure, $K_p$ 183·55 for air.]

$$\therefore \text{ the weight of air present} = \frac{{\cdot}7556}{16{\cdot}25} = {\cdot}0465 \text{ lb.}$$

$$\text{and the total weight of gas + air} \left\{ \begin{array}{l} 0{\cdot}04650 \text{ air.} \\ 0{\cdot}00188 \text{ gas.} \\ \hline 0{\cdot}04838 \text{ lb.} \end{array} \right.$$

$$\text{The ratio } \frac{\text{air}}{\text{gas}} = \text{by volume } \frac{{\cdot}7556}{{\cdot}0822} = \frac{9{\cdot}188}{1}.$$

$$\text{,, \quad ,,} \quad = \text{by weight } \frac{{\cdot}0465}{{\cdot}00188} = \frac{24{\cdot}775}{1}.$$

After combustion, the specific heat at constant volume ($K_v$), and specific heat at constant pressure ($K_p$) will be by Grashof's formulæ—

$$K_p = \frac{{\cdot}2375 \times 9{\cdot}188 + {\cdot}343}{9{\cdot}188 + {\cdot}48} \times 772 = 201{\cdot}75 \text{ ft.-lbs.}$$

$$K_v = \frac{{\cdot}1684 \times 9{\cdot}188 + {\cdot}286}{9{\cdot}188 + {\cdot}48} \times 772 = 146{\cdot}35 \text{ ft.-lbs.}$$

Their difference—

$$(K_p - K_v) = \kappa = 55{\cdot}40 \text{ ft.-lbs.}$$

and the ratio—

$$\frac{K_p}{K_v} = \gamma = \frac{201{\cdot}75}{146{\cdot}35} = 1{\cdot}3785.$$

**Temperatures in Cylinder.**—The temperatures calculated on this basis for the several portions of the stroke will then be as follows:—Assuming, as above, a temperature of 145° F. for the gas and air after admission to the cylinder at A on the mean diagram, and taking the pressure given on that diagram, we shall have a temperature at B after compression:—

$$= T = \frac{p \times v}{53{\cdot}35},$$

if we assume, as is probable, that the mixture behaves in compression approximately as air.

The pressure ($p$) = 67·8 lbs. × 144 = lbs. per sq. ft., the specific volume

$$(v) = \frac{{\cdot}2467 \text{ (clearance)}}{{\cdot}04838 \text{ (weight of gas and air)}} = 5{\cdot}099 \text{ cub. ft. per lb.}$$

$$\therefore T = \frac{67{\cdot}8 \text{ lbs.} \times 144 \times 5{\cdot}099 \text{ cub. ft.}}{53{\cdot}35} = 933^\circ \text{ abs.} = 473^\circ \text{ F.}$$

At C, after heat has been added at constant volume, the temperature will be, with a pressure of 240 lbs. per sq. inch—

$$= \frac{933° \times 240 \text{ lbs.}}{67·8 \text{ lbs.}} = 3{,}302° \text{ abs.} = 2{,}842° \text{ F.}$$

At D, where the volume = ·2617 cub. ft., after further reception of heat at constant pressure, the temperature will be

$$= \frac{3302 \times ·2617}{·2467} = 3{,}503° \text{ abs.} = 3{,}043° \text{ F.}$$

At E, where the pressure on the ideal expansion curve = 48·71 lbs. per sq. inch, and the volume occupied = ·8377 cub. ft., the specific volume of the ·04838 lb. of gas and air

$$= \frac{·8377 \text{ cub. ft.}}{·04838 \text{ cub. ft.}} = 17·31 \text{ cub. ft. per lb.}$$

$$\therefore \text{ the temperature} = \frac{48·71 \text{ lbs.} \times 17·31 \times 144}{55·4\ (\kappa \text{ for mixture})} = 2{,}191° \text{ abs.} = 1{,}731° \text{ F.}$$

**Heat rejected.**—The quantities of heat turned into work, and rejected in the jackets and exhaust will, therefore, be as follows:—

$$13·69 \text{ I.H.P.} = \frac{13·69 \times 33{,}000}{71·2} = 6{,}345 \text{ ft.-lbs. per explosion}$$

turned into work.

Multiplying the water passed through the jackets for each five minutes' interval by the corresponding rise in temperature, the mean value of the heat rejected through the jackets per explosion = 10,825 ft.-lbs.

The heat rejected in the exhaust will evidently be equal to the difference between the internal energy of the gases under conditions E and A, although it must be noted that some portion of the heat thus calculated will pass into the jacket water during release, and will thus be reckoned twice over. The heat account on this basis should, therefore, overbalance.

The heat rejected in exhaust will be—

$K_v\,(2{,}191° - 605°) \times ·04838$ lb. $= 146·35\,(1{,}586) \times ·04838 = 11{,}245$ ft.-lbs. per explosion.

As a check upon this quantity, the reception of heat from B to C at constant volume

$= K_v\,(3{,}302° - 933°) \times ·04838$ lb. $= 146·35\,(2{,}369) \times ·04838 = 16{,}775$ ft.-lbs.

And at constant pressure C to D

$= K_p\,(3{,}503° - 3{,}302°) \times ·04838$ lb. $= 201·75$ ([illegible]) $\times ·04838 = 1{,}971$ ft.-lbs.

During compression, the [illegible] equal to the difference between the internal energies [illegible] end of the process

$= K_v$ (for air) $(933° -$ [illegible] $\times ·04838 = 2{,}066$ ft.-lbs.

The work done during compression where $p\,v^{1\cdot302}$ is constant

$$=\frac{p_1 v_1 - p_2 v_2}{n-1}=\frac{144}{\cdot302}=(67\cdot8 \text{ lbs.} \times \cdot2467 \text{ clearance} - 13\cdot8 \text{ lbs.} \times \cdot8377 \text{ total vol.}) \text{ (where } n = 1\cdot302) = 2{,}465 \text{ ft.-lbs.}$$

Adding together the heat received,

$$16{,}775 + 1{,}971 + 2{,}066 = 20{,}812 \text{ ft.-lbs.},$$

and subtracting the total work above zero pressure,

$$6{,}345 \text{ ft.-lbs.} + 2{,}465 \text{ ft.-lbs.} = 8{,}810 \text{ ft.-lbs.},$$

we have 20,812 − 8,810 = 12,002 ft.-lbs. as the remainder rejected, calculated from D, where expansion commences. During expansion the loss of internal energy

$$= K_v\,(3{,}503^\circ - 2{,}191^\circ)\ \cdot04838 \text{ lbs.} = 146\cdot35\ (1{,}312)\ \cdot04838 = 9{,}288 \text{ ft.-lbs.}$$

The work done

$$= \frac{p_1 v_1 - p_2 v_2}{n-1} \text{ where } n = 1\cdot374 = \frac{240 \times (\cdot2617 - 48\cdot71) \times \cdot8377}{\cdot374} \times 144$$
$$= 8{,}470 \text{ ft.-lbs.}$$

The difference between these quantities will evidently have been passed into the jacket or lost by radiation, and will, therefore, have to be subtracted from the above 12,002 ft.-lbs., in order to give the internal energy remaining to be disposed of at E.

12,002 − (9,288 − 8,470) = 11,184 ft.-lbs., as compared with 11,245 ft.-lbs. by direct calculation.

**Heat Account.**—On the Dr. side of the account we have the heat developed by the perfect combustion of ·001877 lbs. of gas per explosion.

In order to determine the calorific value of the gas, samples were taken, under mercury, at intervals throughout the trial, and analysed by Mr. G. H. Huntly, A.R.C.S., of the State Medicine Laboratory, King's College, London. The analysis is given in detail in Table V. The calorific value is shown in the last column of this table. Taking this in round numbers as 19,200 B.T.U. per lb., we have for the perfect combustion of ·001877 lb. of gas per explosion, ·001877 × 19,200 × 772 * = 27,820 ft.-lbs. developed per explosion, and the heat account works out as given in Table V. It will be seen that the Cr. side overbalances the Dr. side by about 2¼ per cent., from the unavoidable double reckoning of a portion of the heat credited to exhaust.

**Analysis of Exhaust Gases.**—In Table VI. will be found the analysis of the exhaust gases. These were also carefully sampled under mercury. It will be seen that they are quite free from CO, and that the combustion is, therefore, probably complete.

As a check upon the necessarily approximate nature of the sampling, Mr. Huntly has calculated what the exhaust products should be, if combustion takes place with 9·188 volumes of air and 1 volume of the gas analysed above. The result is given in the second column of the same

* 772 = ft.-lbs. per B.T.U. or Joule's Equivalent.

table, and agrees very well as to CO and $CO_2$ with the actual products found. There is, however, considerable excess of oxygen in the calculated, over the found values of the products. This is probably to be accounted for by the difficulty of obtaining a really average sample. The results are, however, worth recording as a close approximation to accuracy.

The oxygen necessary to convert the known value of the hydrogen to water has been allowed for in the calculation, the analysis having been carried out dry.

**Transmission of Heat through Cast-Iron Jacket Wall.**—The total heating surface (the internal surface of cylinder plus the clearance)

$$= 740 \text{ sq. inches} = 5{\cdot}14 \text{ sq. ft.}$$

Therefore heat transmitted to jackets per sq. ft. per hour

$$= \frac{10{,}825 \times 71{\cdot}24 \times 60 \times 144}{772 \times 740} = 11{,}660 \text{ B.T.U. per hour.}$$

But transmission probably only takes place during the out stroke, therefore the rate of transmission for the revolutions per hour = 9,750, and the explosions = 4273·5 per hour

$$= \frac{11{,}660 \text{ B.T.U.} \times 9{,}750 \times 2}{4273{\cdot}5} = 53{,}190 \text{ B.T.U. per hour} = 886 \text{ B.T.U. per min.}$$

The cooling surface (external surface in jacket space of cylinder metal)

$$= 926{\cdot}6 \text{ sq. inches} = 6{\cdot}43 \text{ sq. ft.}$$

Therefore the rate of transmission per sq. ft. of cooling surface

$$= \frac{53{,}190 \times 5{\cdot}14}{6{\cdot}43} = 42{,}525 \text{ B.T.U. per hour} = 709 \text{ B.T.U. per sq. ft. per min.}$$

Taking the mean temperature of the jacket water as equal to 90° F., and the temperature of the gases when most of the heat would pass into the jackets, as equal to 2,900° F. the rate of transmission, by formula given by Rankine, should be approximately :—

$$\frac{(2{,}900^\circ - 90^\circ)^2}{160} = 49{,}350 \text{ B.T.U. per hour per sq. ft.}$$

which very closely agrees with the actual rate of transmission as above.

The thickness of the cast-iron cylinder wall is about $\frac{3}{4}''$. The *internal* surface of the cylinder in contact with the hot gases is called the *heating* surface; the *external* surface of the cylinder in contact with the jacket water is called the *cooling* surface.

A graphic diagram is added at Fig. 136, giving on a time basis the following particulars of the trial :—Exp[illegible]ions per minute, revolutions per minute, mean pressure, indi[illegible] horse-p[illegible] [illegible]rake horse-power, gas consumption, heat rejected in jack[illegible] tot[illegible] [illegible], total revolutions, total water [illegible] in millions of foot-pounds, [illegible]fessor Capper on the 2nd [illegible]ame load, results were [illegible]sent trial.

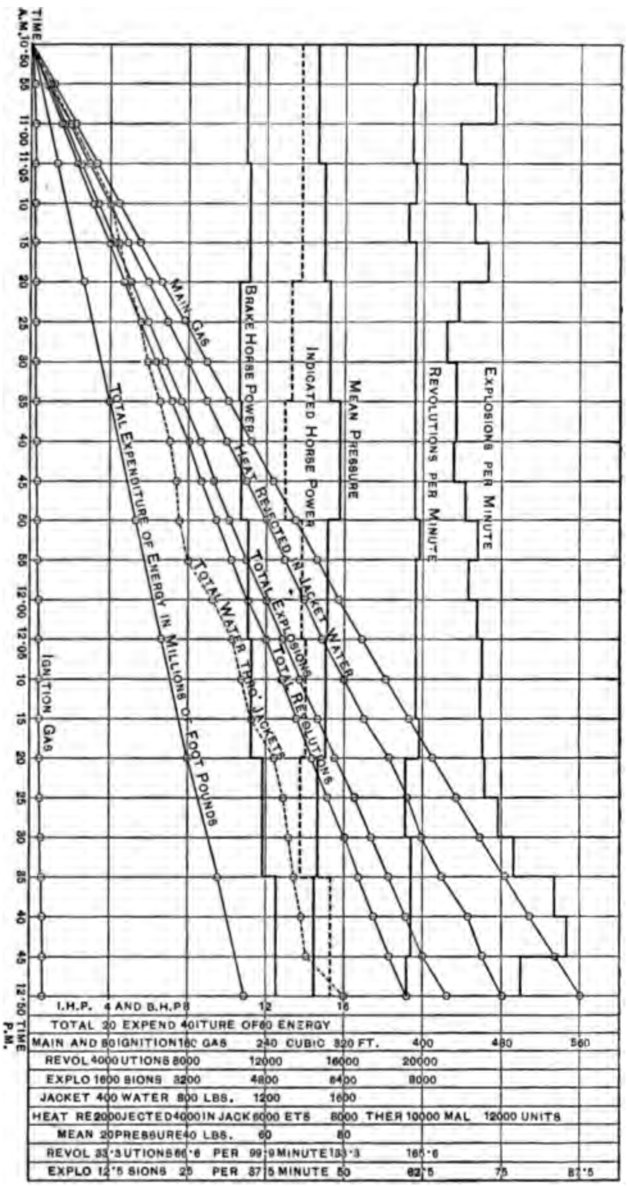


Fig. 136.—Results of Trial on a Time Base—Graphic Representation.

## TABLE I.

RESULTS OF TWO HOURS' TEST ON 8½″ × 18″ OTTO GAS ENGINE—*London Gas.*

| | | | |
|---|---|---|---|
| 1. Duration of test in hours, . . | 1st hour | 2nd hour | mean |
| 2. Number of indicator diagrams taken, | 9 | 9 | 18 |
| 3. Average initial pressure above atmosphere in lbs., from mean diagram, | 227·5 | 225·6 | 226·5 |
| 4. Average mean pressure during working stroke from diagram in lbs., . | 74·15 | 74·98 | 74·56 |
| 5. Average mean pressure during pumping stroke in lbs., . . . . . | 2 | 2 | 2 |
| 6. Net average pressure (4 − 5) in lbs., | 72·15 | 72·98 | 72·56 |
| 7. Revolutions per minute, . . . | 162·6 | 162·4 | 162·5 |
| 8. Explosions per minute by counter, . | 69·06 | 73·42 | 71·2 |
| 9. Indicated H.P. for working stroke, | 13·20 | 14·15 | 13·69 |
| 10. Indicated H.P. net (including pumping stroke), . . . . . . | 12·85 | 13·8 | 13·32 |
| 11. Load on rope brake in lbs., . . | 202·0 | 202·0 | 202·0 |
| 12. Reading of spring balance, net lbs., | 71·2 | 65·3 | 68·2 |
| Difference, . . . . | 130·8 | 136·7 | 133·8 |
| 13. Radius of flywheel, ins., . . . | 33 | 33 | 33 |
| 14. Brake H.P., . . . . . . | 10·96 | 11·71 | 11·33 |
| 15. Mechanical efficiency of engine, per cent. line 10 and 14, . . . | 85·3 | 84·85 | 85·06 |
| 16. Gas used per hour (without ignition) in cub. ft., . . . . . . | 271·9 | 287·6 | 279·7 |
| 17. Gas used per hour (ignition) in cub. ft., . . . . . . | 5·94 | 5·96 | 5·95 |
| 18. Total gas used (main and ignition) in cub. ft., . . . . . . | 277·84 | 293·56 | 285·65 |
| 19. Pressure of gas at meter, ins. of water, . . . . . . . | 1·7 | 1·65 | 1·68 |
| 20. Temperature of gas at meter in degrees F., . . . . . . | 58 | 58 | 58 |
| 21. Gas per I.H.P. per hour in cub. ft., . . . . . . . | 20·6 | 20·3 | 20·45 |
| 22. Gas per I.H.P. per hour (including ignition) in cub. ft., . . . | 21·05 | [illegible] | 20·87 |
| 23. Gas per brake H.P. per hour in cub. ft., . . . . . | [illegible] | [illegible] | 24·7 |
| 24. Gas per B.H.P. per hour (including ignition) in cub. ft., . | [illegible] | [illegible] | 25·22 |

## TABLE II.

RESULTS OF TEST—*Continued.*

| | | |
|---|---|---|
| | 1. Town gas used per explosion (volume through meter), . . . . . . . . | ·06544 cub. ft. |
| | 2. Pounds gas used per explosion, . . . . | ·001877 lbs. |
| | 3. Calorific value of London gas per explosion, calculated from analysis, thermal units, . | 36·04 B.T.U. |
| | 4. Mechanical equivalent of ditto, . . . | 27,820 ft-lbs. |
| | 5. Work done on charge during compression, . | 2,465 ,, |
| | 6. Work done by charge calculated gross, . . | 9,059 ,, |
| | 7. Net work done by charge in ideal process, A,B,C,D,E, Fig. 135, . . . . . . | 6,594 ,, |
| | 8. Actual net work done, mean of all indicator diagrams, . . . . . . . . . | 6,345 ,, |
| Efficiencies. | 9. Efficiency of engine (actual) $\frac{\text{Heat turned into work}}{\text{Whole heat expended}} = \frac{6{,}345}{27{,}820}$ . . | ·228 per cent. |
| | 10. Efficiency of engine (maximum theoretical) $\frac{T_1 - T_0}{T_1} = \frac{3{,}503^\circ - 605^\circ}{3{,}503^\circ}$ . . . . . | ·827 ,, |
| | 11. $\frac{\text{Actual efficiency}}{\text{Maximum theoretical efficiency}} = \frac{0{\cdot}228}{0{\cdot}827}$ . . | ·275 ,, |
| Transmission of heat. | 12. Rate of transmission of heat through cylinder wall, per sq. ft. (internal) surface per hour, . . . . . . . . . . . | 53,190 B.T.U. |
| | 13. Do. do. per sq. ft. (external) surface of cylinder per hour, . . . . . . | 42,525 ,, |
| | 14. Do. do. per sq. ft. (internal) surface of cylinder per minute, . . . . . . | 886 ,, |
| | 15. Do. do. per sq. ft. (external) surface of cylinder per minute, . . . . . | 709 ,, |

## TABLE III.

RESULTS OF TEST—*Continued.* See mean indicator diagram for A,B,C,D,E, Fig. 135, p. 356.

| | | |
|---|---|---|
| Assumed temperature of gas and air after entering the cylinder (A), . . . . . . . | 145° F. | 605° abs. |
| Calculated temperature after compression (B), . | 473° F. | 933° ,, |
| Calculated temperature after reaching maximum pressure (C), . . . . . . . . | 2,842° F. | 3,302° ,, |
| Calculated temperature after beginning to fall in pressure (D), . . . . . . . . | 3,043° F. | 3,503° ,, |
| Calculated temperature at end of expansion (E), | 1,731° F. | 2,191° ,, |
| Mechanical equivalent of heat carried off by jacket water per explosion, . . . | 10,825 ft.-lbs. | |
| Jacket water. In-going temperature, . . . . | 42°·2 F. | |
| Jacket water. Out-going temperature, . . . | 139°·8 F. | |
| Difference (rise), . . . | 97°·6 | |

## TABLE IV.

RESULTS OF TEST—*Continued.* See Indicator Diagrams for A,B,C,D,E, Fig. 135.

| | | Ft.-Lbs. |
|---|---|---|
| Heat taken up by charge during compression, A to B, . . . . | | 2,066 |
| ,, ,, ,, increase of pressure at constant volume, C to D, . . . . | | 16,775 |
| ,, ,, ,, increase of volume at constant pressure, D to E, . . . . | | 1,971 |
| Total, . . . . . . . . | | 20,812 |
| Total amount of heat turned into work above zero pressure, . . . . . . . . 6,345 + 2,465 = | 8,810 | |
| Heat rejected to jacket during expansion, add . . . . | 818 | |
| | | 9,628 |
| Difference = heat rejected in exhaust, . | | 11,184 |
| Heat rejected in exhaust by direct calculation, . . . . . | | 11,245 |

## TABLE V.

HEAT BALANCE SHEET.

| | Ft.-Lbs. per Explosion. | | Ft.-Lbs. per Explosion. |
|---|---|---|---|
| Total heat due to perfect combustion of ·001877 lb. of gas, . . . . . | 27,820 | Heat turned into work, . | 6,345 |
| | | ,, rejected in jacket water, | 10,825 |
| | | ,, ,, exhaust, . | 11,245 |
| | 27,820 | | 28,415 |

PROPORTIONAL VALUES.

| | Percentage of whole heat of combustion. |
|---|---|
| Net work done, . . . . . . . . . | 22·8 |
| Heat rejected in jacket water, . . . . . . | 38·9 |
| ,, ,, exhaust, . . . . . . . | 40·5 |
| (2·2 per cent. over balance for reasons given) | 102·2 |

## TABLE VI.

ANALYSIS OF LONDON GAS USED. (Gas Light and Coke Co.)

| | Volume per cent. | Weight in one cub. ft. of gas. | Proportion by weight. | Calorific value per lb. | Calorific value in 1 lb. of gas. |
|---|---|---|---|---|---|
| $CH_4$, . . . . . | 31·5 | ·01408 | ·4279 | 23,200 ft.-lbs. | 9,928 T.U. |
| Olefines, $C_2H_4+C_4H_8$, | 5·1 | ·00599 | ·1821 | 21,200 ,, | 3,861 ,, |
| Hydrogen, . . . . | 51·2 | ·00286 | ·0869 | 52,500 ,, | 4,562 ,, |
| CO, . . . . . | 7·7 | ·00603 | ·1833 | 4,300 ,, | 788 ,, |
| Nitrogen, . . . . | 3·0 | ·00235 | ·0714 | ... | ... |
| $CO_2$ and Oxygen, . | 1·3 | ·00159 | [illegible] | ... | ... |
| | ... | ·03290 | [illegible] | ... | 10,129 T.U. |

TABLE VII.

ANALYSIS OF EXHAUST GASES TAKEN AS DRY.

| | Per cent. volume. | |
|---|---|---|
| | Experiment. | Calculated. |
| $CO_2$, Carbon dioxide, . . . . . . . | 6·76 | 6·45 |
| $O_2$, Oxygen, . . . . . . . . | 6·14 | 8·94 |
| CO, Carbon monoxide, . . . . . . | nil. | nil. |
| $N_2$, Nitrogen (by difference), . . . . | 87·10 | 84·6 |
| By volume, . . . . | 100·00 | 100·00 |

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## SECTION B.

### ABSTRACT TRANSLATION OF BEAU DE ROCHAS' CYCLE.
(French Patent, 1862.)

#### CONCERNING COMPRESSION IN A GAS ENGINE.

. . . . . The conditions for perfectly utilising the elastic force of gas in an engine are four in number :—

I. The largest possible cylinder volume with the minimum boundary surface.
II. The greatest possible working speed.
III. Greatest possible number of expansions.
IV. Greatest possible pressure at the beginning of expansion.

The characteristic of gases to disperse over a given area can be turned to excellent account in pipes, but is, on the contrary, evidently an obstacle to the utilisation of the elastic force developed in the gaseous mass. It has been shown [in a former part of the patent] that in pipes the utilisation—that is, the heat transmitted—is in proportion to the diameter of the pipe. In cylinders, therefore, the loss would be in inverse ratio to the diameter, but this only applies to cylinders of very small diameter, and the loss really diminishes more rapidly in proportion to the increase in diameter. Thus the typical design, which, for a given expenditure of gas, assigns a cylinder of the largest diameter, will in this respect utilise the most heat. We may also conclude that, as far as possible, only one gas cylinder should be used in each separate engine.

But the loss of heat in the gas depends also on the time. Other things being equal, the cooling will be greater the slower the speed. Now greater speed seems to entail a cylinder of small volume ; but this apparent contradiction disappears if we remember that, for a given consumption of gas, the stroke is not necessarily and invariably limited to the volume of the cylinder.

In utilising the elastic force of gas it is necessary, as with steam, that expansion should be prolonged as much as possible. In the typical design

described above, there is a maximum of expansion for each particular case, although the effect is necessarily limited. The arrangement will, therefore, give the best result, which restores to the motor what may be called its liberty of expansion, that is to say, the power of expanding as much as may be thought desirable, within practical working limits.

Lastly, the utilisation of the elastic force of the gas depends upon a function closely allied to prolonged expansion and its advantages. This is the pressure, which should be as great as possible, to produce the maximum effect. Here the question clearly is to obtain expansion of the gases when they are hot, after compressing them while cold. This is to a certain extent an inverse method of prolonging expansion to that employed when a vacuum is formed. The latter process is not at all suited to gases, because all such compression necessitates an equivalent condensation, and even supposing the gases were combustible, it would be impossible to heat them instantaneously.

Theoretically, therefore, it is possible to utilise the elastic force of the gases without limit, by compressing them indefinitely before heating, just as the elastic force of steam may be utilised without limit, by prolonging expansion indefinitely. Practically an impassable limit is attained, as soon as the elevation of temperature due to previous compression causes spontaneous combustion. If compression be then continued, the work done by it would be represented by expansion prolonged to the same point, less the loss caused by all useless work. The natural limit is here reached, and the arrangement which best attains it will utilise to the most advantage the heat supplied.

The question of heat utilisation being thus stated, the only really practical arrangement is to use a single cylinder, first that the volume may be as large as possible, and next to reduce the resistance of the gas to a minimum. The following operations must then take place on one side of the cylinder, during one period of four consecutive strokes:—

I. Drawing in the charge during one whole piston stroke.

II. Compression during the following stroke.

III. Inflammation at the dead point, and expansion during the third stroke.

IV. Discharge of the burnt gases from the cylinder during the fourth and last stroke.

The same operations being afterwards repeated on the other side of the cylinder in the same number of piston strokes, the result will be a particular type of single-acting, or half-acting engine, so to speak, which will evidently afford the largest possible cylinder, and what is still more important, previous compression. The piston speed will also be greatest in proportion to the diameter, because the work is performed in one single stroke, which would otherwise occupy two. Clearly it is impossible to do more.

As the temperature of the gases coming from a furnace is practically constant, and that of the external atmosphere varies relatively only within narrow limits, the initial temperature of the mixture at the moment of admission into the cylinder will also be practically constant. It will, therefore, be possible to determine the limit of compression at which combustion is produced, and to make the design of the engine conform to it. Thus the maximum effect will always be obtained, for each proportional dilution of the combustible. At the [illegible] there will be no necessity to use electricity, [illegible] the starting [illegible] engine being determined by the action of [illegible]), the gases [illegible] admitted only when the speed has become [illegible] to [illegible] inflammation. In any case compre[illegible] to mix [illegible] thoroughly and by raising its temperatu[illegible] favourable [illegible] combustion. If the initial tempera[illegible] to a pressure of 5 or 6

atmospheres, inflammation would be spontaneously produced if the gases were compressed to about a quarter of the original volume, the effect of loss of heat being neglected. After complete inflammation the pressure would be hardly 30 atmospheres, and as combustion would be effected without excess of air, the pressure would in any other case (*i.e.*, where an excess of air was admitted) be necessarily less. Probably, therefore, in many cases, the absolute limit of utilisation of the heat may be attained.

We may sum up the question by saying that, although the typical arrangement here described can be most completely and perfectly adapted to the utilisation of the elastic force developed by combustion at constant volume in the gaseous mass, it is quite simple. It is perhaps rather a convenience than a necessity to use lift-valve distribution. This is generally the best method, and nothing proves that it may not be applied to the four-cycle type of engine.

## SECTION C.

List of Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1884.

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Hargreaves, | 325 | Jan. | 2, | 1884, | Valves and general. |
| Skene, | 454 | ,, | 2, | ,, | Compressing and igniting. |
| Steel and Whitehead, | 560 | ,, | 3, | ,, | Starting and miscellaneous. |
| Sterne, | 1,373 | ,, | 12, | ,, | Silencing. |
| Wirth (Bernstein), | 1,457 | ,, | 15, | ,, | Producing motive power. |
| Rodgerson, | 2,088 | ,, | 25, | ,, | Compression and igniting. |
| Ainsworth, | 2,089 | ,, | 25, | ,, | Cylinders. |
| Ofenderson, | 2,135 | ,, | 25, | ,, | ... |
| Davy, | 3,778 | Feb. | 2, | ,, | Cylinders and valves. |
| Woodhead, | 2,715 | ,, | 5, | ,, | Starting and miscellaneous. |
| Clayton, | 2,854 | ,, | 6, | ,, | Compression and exhausting. |
| Fielding, | 2,933 | ,, | 8, | ,, | ,, ,, |
| Cobham and Gilliespie, | 3,495 | ,, | 18, | ,, | Noncompression and valves. |
| Holt and Crossley, | 3,537 | ,, | 18, | ,, | Starting. |
| Griffin, | 3,758 | ,, | 22, | ,, | Cylinder and stuffing boxes. |
| Holt, | 3,893 | ,, | 25, | ,, | Compressing pump. |
| Johnson, | 3,986 | ,, | 26, | ,, | Igniting. |
| Malam and King, | 4,391 | March | 5, | ,, | General. |
| Munden, | 4,591 | ,, | 8, | ,, | Exhausting. |
| Pollock, | 4,639 | ,, | 10, | ,, | Igniting and valves. |
| Wirth (Söhnlien), | 4,736 | ,, | 11, | ,, | Petroleum motor. |
| Spencer, | 4,776 | ,, | 12, | ,, | Exhausting. |
| Crossley, | 4,777 | ,, | 12, | ,, | Compression. |
| Weatherhogg, | 4,880 | ,, | 14, | ,, | ,, |
| Hill and Hill, | 5,007 | ,, | 17, | ,, | Igniting, gas or vapour. |
| Johns and Johns, | 5,302 | ,, | 22, | ,, | Rotatory gas engine. |
| ,, ,, | 5,303 | ,, | 22, | ,, | ,, ,, |
| J. Magee, | 5,365 | ,, | 24, | ,, | Valves. |
| Dewhurst, | 5,412 | ,, | 24, | ,, | ,, |
| Park, | 5,435 | ,, | 25, | ,, | Rotatory gas engine. |
| J. Magee, | 5,484 | ,, | 26, | ,, | Valves. |
| ,, | 5,636 | ,, | 29, | ,, | ,, |

| | | | | |
|---|---|---|---|---|
| | | | | Speciality. |
| Butcher, . . . . | 5,641 | March 29, | 1884, | Igniting and valves. |
| Linford and Piercey, . | 5,797 | April 1, | ,, | Igniting. |
| Holt, . . . . . | 6,039 | ,, 7, | ,, | General. |
| Wiegand, . . . . | 6,662 | ,, 22, | ,, | Igniting. |
| Mugniers, . . . . | 6,678 | ,, 22, | ,, | ,, and General. |
| M'Niel, . . . . | 6,784 | ,, 25, | ,, | Tramway loco. (gas). |
| King, . . . . . | 7,284 | May 6, | ,, | Compression. |
| ,, . . . . . | 7,288 | ,, 6, | ,, | ,, |
| Holt, . . . . . | 8,211 | ,, 26, | ,, | Compound gas engine. |
| Sombart, . . . . | 8,232 | ,, 26, | ,, | Compression. |
| Green, . . . . | 8,489 | ,, 31, | ,, | Supplying gas to engine. |
| Rogers, . . . . | 8,565 | June 4, | ,, | Miscellaneous. |
| Shaw, . . . . | 8,579 | ,, 4, | ,, | Compression. |
| Crossley, . . . . | 8,637 | ,, 5, | ,, | Igniting (The Otto). |
| Ainsworth, . . . | 8,960 | ,, 14, | ,, | Cylinder. |
| Guthrie. . . . . | 9,001 | ,, 16, | ,, | Igniting. |
| Grath (Daimler), . | 9,112 | ,, 17, | ,, | Gas or oil motors. |
| Williamson, Malam, and Ireland, . . | 9,167 | ,, 16, | ,, | Valves and gear. |
| Magee, . . . . | 9,544 | ,, 28, | ,, | Starting. |
| Welch and Rapier, . | 9,645 | July 1, | ,, | Exhausting. |
| Capitaine, . . . . | 9,949 | ,, 9, | ,, | Compression. |
| Norrington, . . . | 10,062 | ,, 11, | ,, | Assisting starting. |
| Guthrie, . . . . | 10,483 | ,, 16, | ,, | Caloric engine. |
| Shaw, . . . . | 10,885 | August 2, | ,, | Compression. |
| Butterworth, . . . | 11,086 | ,, 9, | ,, | Noncompression. |
| Justice, . . . . | 11,361 | ,, 16, | ,, | General. |
| Crossley, . . . . | 11,578 | ,, 23, | ,, | Igniting. |
| G. Magee and M'Ghee, | 11,596 | ,, 25, | ,, | Gas motor. |
| Douglas, . . . . | 11,750 | ,, 29, | ,, | Exhausting. |
| Clark (Hopkins), . | 11,837 | Sept. 1, | ,, | Noncompression and Igniting. |
| J. Magee, . . . . | 12,023 | ,, 5, | ,, | Igniting. |
| Griffiths, . . . . | 12,201 | ,, 9, | ,, | ,, |
| Davy, . . . . | 12,264 | ,, 10, | ,, | Cylinders, valves and exhausting. |
| Brine, . . . . | 12,312 | ,, 12, | ,, | Igniting. |
| Dougill, . . . . | 12,318 | ,, 12, | ,, | Valves and gear. |
| Purnell, . . . . | 12,431 | ,, 15, | ,, | Compression. |
| Hill and Hill, . . | 12,603 | ,, 19, | ,, | Noncompression gas or vapour. |
| Tellier, . . . . | 12,640 | ,, 20, | ,, | General. |
| Reddie, . . . . | 12,714 | ,, 23, | ,, | ,, |
| Wilson, . . . . | 12,776 | ,, 25, | ,, | Tramway gas engine. |
| ,, . . . . . | 12,777 | ,, 25, | ,, | ,, ,, |
| Davy, . . . . | 12,842 | ,, 26, | ,, | Cylinders and valves. |
| Andrews, . . . . | 13,221 | Oct. 6, | ,, | General. |
| Redfern (M'Donough), | 13,283 | ,, 7, | ,, | Compression and igniting. |
| Parker, . . . . | 13,766 | ,, 17, | ,, | ,, ,, |
| Lawson, . . . . | 13,935 | ,, 21, | ,, | Exhausting pump. |
| Griffin, . . . . | 14,311 | ,, 29, | ,, | Igniting. |
| Browett, . . . . | 14,341 | ,, 30, | ,, | Exhausting. |
| Prentice and Prentice, | 14,512 | Nov. 3, | ,, | Starting and igniting. |
| M'Gillivray, . . . | 14,765 | ,, 8, | ,, | Igniting, valves and gear. |
| Holt and Crossley, . | 15,311 | ,, 20, | ,, | Compound gas engine. |
| Holt, . . . . . | 15,312 | ,, 20, | ,, | Compression. |
| Newton, . . . . | 15,633 | ,, 27, | ,, | ,, |
| Bénier, . . . . | 16,131 | Dec. 1, | ,, | Hot-air engine. |
| Holt, . . . . . | 16,250 | ,, 10, | ,, | |

| | | | | Speciality. |
|---|---|---|---|---|
| Atkinson, . . . | 16,404 | Dec. | 13, 1884, | Compression. |
| Müller (Adkins and Angus), . . . | 16,634 | ,, | 18, ,, | Igniting. |
| Regan, . . . | 16,890 | ,, | 24, ,, | Electro gas engine. |
| Imray (Barnes and Danks), . . . | 16,947 | ,, | 27, ,, | Starting. |
| Radford (Martin), . | 16,992 | ,, | 29, ,, | Hot air engine. |
| Malam and others, . | 17,029 | ,, | 30, ,, | Silencing. |

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List of Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for Year 1885.

| | | | | Speciality. |
|---|---|---|---|---|
| Johnson (Lenoir), . | 610 | Jan. | 1, 1885, | General and Igniting. |
| Myer, . . . . | 848 | ,, | 21, ,, | Valves and gear. |
| Pinkney, . . . | 1,218 | ,, | 28, ,, | General. |
| Simon, . . . . | 1,363 | ,, | 30, ,, | Compression. |
| Asher and Buttress, . | 1,424 | Feb. | 2, ,, | Liquid fuel vapour. |
| Kempster, . . . | 1,581 | ,, | 5, ,, | Hydrocarbon. |
| King, . . . . | 1,700 | ,, | 7, ,, | Compression. |
| Wright and Charlton, | 1,703 | ,, | 7, ,, | Petroleum. |
| Atkinson, . . . | 2,712 | ,, | 28, ,, | Valves and gear. |
| Beechey, . . . | 3,199 | March | 11, ,, | Compression and igniting. |
| Spiel, . . . . | 3,414 | ,, | 17, ,, | Petroleum. |
| Pope, . . . . | 3,471 | ,, | 17, ,, | Compression. |
| Holt, . . . . | 3,747 | ,, | 23, ,, | General. |
| Atkinson, . . . | 3,785 | ,, | 24, ,, | Compression. |
| Mackenzie, . . . | 3,971 | ,, | 28, ,, | Igniting. |
| Daimler, . . . | 4,315 | April | 7, ,, | Petroleum. |
| Garrett, . . . | 4,684 | ,, | 16, ,, | Valves and gear. |
| Bickerton, . . . | 5,519 | May | 5, ,, | General. |
| Andrews, . . . | 5,561 | ,, | 6, ,, | Compression and governing. |
| Mills, . . . . | 5,971 | ,, | 15, ,, | ,, ,, |
| Rigg, . . . . | 6,047 | ,, | 16, ,, | Miscellaneous. |
| Weatherhogg, . . | 6,565 | ,, | 30, ,, | Compression and igniting. |
| M'Ghee and Magee, . | 6,763 | June | 3, ,, | Miscellaneous ,, |
| MacGeorge, . . | 6,880 | ,, | 5, ,, | General. |
| Campbell, . . . | 6,990 | ,, | 9, ,, | Compression. |
| Warsop and Hill, . | 7,104 | ,, | 11, ,, | Igniting. |
| Capitaine and Brunler, . . . | 7,500 | ,, | 19, ,, | Compression. |
| Dowson, . . . | 7,920 | ,, | 30, ,, | Igniting. |
| Newton, . . . | 7,929 | ,, | 30, ,, | ,, and cylinders and stuffing boxes. |
| Crossley, . . . | 8,134 | July | 4, ,, | Compression and exhausting. |
| Wordsworth and Wolstenholme, . | 8,160 | ,, | 6, ,, | Compression and governing. |
| Humes, . . . | 8,411 | ,, | 11, ,, | Hydrocarbon, valves and gear. |
| Newton (Treeton), . | 8,584 | ,, | 15, ,, | Valves, gear and governing. |
| Sturgeon, . . . | 8,897 | ,, | 23, ,, | Compression. |
| Calton (Hortig), . . | 9,801 | Aug. | 8, ,, | Non-compression and exhausting. |

| | | | | Speciality. |
|---|---|---|---|---|
| Priestman and Priestman, | 10,227 | Aug. | 28, 1885, | Hydrocarbon. |
| Justice (Hale), | 10,401 | Sept. | 2, ,, | Compression, valves and gear. |
| Daimler, | 10,786 | ,, | 11, ,, | Petroleum, road vehicle. |
| Grading and Harding, | 11,215 | ,, | 21, ,, | Igniting. |
| Redfern (Swyer), | 11,290 | ,, | 22, ,, | Petroleum. |
| Clark (Economic Motor Co.), | 11,294 | ,, | 22, ,, | Non-compression and igniting. |
| Magee, | 11,422 | ,, | 25, ,, | Governing. |
| Cattrall and Stout, | 11,555 | ,, | 29, ,, | ,, |
| Gillot, | 11,558 | ,, | 29, ,, | Compression. |
| Abel (Gas Motoren-Fabrik Deutz), | 11,933 | Oct. | 10, ,, | Igniting. |
| Southall, | 12,424 | ,, | 17, ,, | Compression. |
| Clark (Economic Motor Co.), | 12,483 | ,, | 19, ,, | Igniting. |
| Schiltz, | 12,896 | ,, | 27, ,, | Petroleum. |
| Grath (Daimler), | 13,163 | ,, | 31, ,, | Gas and oil. |
| Dinsmore, | 13,309 | Nov. | 4, ,, | Compression, cylinder and stuffing boxes. |
| Nash, | 14,394 | ,, | 24, ,, | Liquid fuel vapour. |
| Burgh and Gray, | 15,194 | Dec. | 10, ,, | Non-compression and igniting. |
| Atkinson, | 15,243 | ,, | 11, ,, | Starting. |
| Ruckteshell, | 15,475 | ,, | 16, ,, | Nitro cellulose. |
| Johnson and others, | 15,710 | ,, | 21, ,, | Governing. |
| Rogers, | 15,737 | ,, | 22, ,, | Compression and igniting. |
| Bickerton, | 15,845 | ,, | 24, ,, | Starting and compression. |
| Willcox, | 15,874 | ,, | 24, ,, | Hot air ,, ,, |
| ,, | 15,875 | ,, | 24, ,, | Cylinder and stuffing boxes. |
| ,, | 15,876 | ,, | 24, ,, | ,, ,, |
| Wimshurst, | 15,936 | ,, | 28, ,, | General design. |

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## Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1886.

| | | | | Speciality. |
|---|---|---|---|---|
| Johnson and others, | 11 | Jan. | 1, 1886, | Eectric ignition. |
| Butterworth, | 207 | ,, | 6, ,, | Compression and valves. |
| Fairweather, | 477 | ,, | 12, ,, | Hot air and gas mixed. |
| ,, | 478 | ,, | 12, ,, | ,, ,, |
| Nash, | 493 | ,, | 12, ,, | Double acting. |
| Magee, | 665 | ,, | 15, ,, | Valves for exhausting. |
| Brine, | 942 | ,, | 21, ,, | Road vehicle. |
| Priestman and Priestman, | 1,394 | ,, | 30, ,, | Hydrocarbon. |
| M'Ghee, | 1,433 | Feb. | 1, ,, | Igniting and valves. |
| Humes, | 1,464 | ,, | 1, ,, | Hydrocarbon and igniting. |
| Welch and Rook, | 1,696 | ,, | 5, ,, | General design. |
| Shillito, | 1,797 | ,, | 6, ,, | Cooling cylinders. |
| Haddan, | 1,958 | ,, | 10, ,, | General design and valves. |
| Eimecke, | 2,122 | ,, | 13. ,, | Hot air and valves. |
| Capitaine and Bruuler, | 2,140 | ,, | 13, ,, | Petroleum. |

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Skene, . . . . | 2,174 | Feb. | 15, | 1886, | Igniting. |
| Leigh, . . . . | 2,272 | ,, | 16, | ,, | Regulating supply of gas. |
| Shaw, . . . . | 2,447 | ,, | 19, | ,, | Igniting and valves. |
| Boulton and Perrett, . | 2,653 | ,, | 23, | ,, | Gas and steam, opposite sides. |
| Millburn and Hannan, | 2,993 | March | 3, | ,, | Miscellaneous and governing. |
| Deacon, . . . . | 3,010 | ,, | 3, | ,, | Hot air, valves and gear. |
| Fielding, . . . . | 3,402 | ,, | 10, | ,, | Double cylinder and igniting. |
| Davy, . . . . | 3,473 | ,, | 11, | ,, | Isolating walls of cylinder. |
| Atkinson, . . . . | 3,522 | ,, | 12, | ,, | General design. |
| Neil, . . . . . | 4,234 | ,, | 26, | ,, | Varying volume gas mixtures. |
| Ruckteshell, . . . | 4,349 | Dec. | 16, | 1885, | Explosive compound. |
| Dawson, . . . . | 4,460 | March | 30, | 1886, | Double and single acting. |
| Hutchinson, . . . | 4,785 | April | 6, | ,, | Petroleum. |
| Justice, . . . . | 4,881 | ,, | 7, | ,, | Combined gas engine and water pump. |
| Abel, . . . . . | 5,804 | ,, | 28, | ,, | General design and valves. |
| Humes, . . . . | 5,597 | ,, | 24, | ,, | Hydrocarbon, and to prevent back ignition. |
| Bernardi, . . . . | 5,665 | ,, | 24, | ,, | Igniting. |
| Benz, . . . . . | 5,789 | ,, | 28, | ,, | Petroleum vehicle. |
| Redfern, . . . . | 6,161 | May | 6, | ,, | Gas producer and motor. |
| Leigh, . . . . | 6,165 | ,, | 6, | ,, | Valves and gear. |
| Charlton and Wright, | 6,551 | ,, | 5, | ,, | Petroleum and igniting. |
| Gilliespie, . . . . | 6,612 | ,, | 17, | ,, | Valves. |
| Nash, . . . . . | 6,670 | ,, | 18, | ,, | Cylinders and stuffing boxes. |
| Rollason, . . . . | 7,427 | June | 2, | ,, | ,, ,, |
| Nixon, . . . . | 7,658 | ,, | 8, | ,, | Double piston. |
| Butterworth, . . . | 7,936 | ,, | 15, | ,, | Combustible gas motor. |
| Reed, . . . . . | 7,967 | ,, | 15, | ,, | Hot air. |
| Roots, . . . . | 8,210 | ,, | 22, | ,, | Petroleum and ignition. |
| Weatherhogg, . . . | 8,436 | ,, | 26, | ,, | Petroleum, ignition, and valves. |
| Fielding, . . . . | 9,563 | July, | 23, | ,, | Ignition. |
| Johnson, . . . . | 9,598 | ,, | 24, | ,, | Carburetter for gas engine. |
| Beeker, . . . . | 9,704 | ,, | 27, | ,, | Hot gases and steam. |
| Crowe and Crowe, . | 9,727 | ,, | 28, | ,, | Gas caloric. |
| Stuart, . . . . | 9,866 | ,, | 31, | ,, | Combining explosive fluids. |
| Otto, . . . . . | 9,941 | Aug. | 3, | ,, | Furnace by compressed air. |
| Oke, . . . . . | 10,034 | ,, | 5, | ,, | Hot air. |
| Boys and Cuninghame, . | 10,332 | ,, | 12, | ,, | Silencer. |
| Schiltz, . . . . | 10,480 | ,, | 16, | ,, | Petroleum and igniting. |
| Boyd, . . . . | 11,246 | Sept. | 4, | ,, | Internal combustion. |
| Humes, . . . . | 11,269 | ,, | 4, | ,, | Hydrocarbon and starting. |
| Boult, . . . . | 11,576 | ,, | 11, | ,, | General and carburetter. |
| Turnbull, . . . . | 11,833 | ,, | 17, | ,, | Manufacturer of gas for motors. |
| Hutchinson, . . . | 12,068 | ,, | 22, | ,, | Petroleum (Swan design). |
| Butterworth, . . . | 12,134 | ,, | 24, | ,, | General design. |
| Robinson, . . . . | 12,346 | ,, | 29, | ,, | Hot air. |
| Rollason, . . . . | 12,368 | ,, | 29, | ,, | Miscellaneous and mixture. |
| Sutcliffe, . . . . | 12,640 | Oct. | 5, | ,, | Utilising waste heat. |
| Nobilings, . . . . | 12,883 | ,, | 9, | ,, | Caloric and valves. |
| Clerk, . . . . | 12,912 | ,, | 11, | ,, | Petroleum and valves. |

| | | | | Speciality. |
|---|---|---|---|---|
| Humes, . . . | 13,229 | Oct. | 16, 1886, | Hydrocarbon. |
| Macallam, . . . | 13,517 | ,, | 22, ,, | Propulsion of vessels by explosion. |
| Ruckhill, . . . | 13,655 | ,, | 25, ,, | Guards for flywheels. |
| Newton (Murray), . | 13,727 | ,, | 26, ,, | General design, igniting and valves. |
| Daimler, . . . | 14,034 | Nov. | 1, ,, | Marine propulsion by gas or petroleum. |
| M'Ghee, . . . | 14,578 | ,, | 11, ,, | Miscellaneous. |
| Collier, . . . | 15,066 | ,, | 19, ,, | Internal combustion, hydrocarbon. |
| Robson, . . . | 15,307 | ,, | 24, ,, | General design. |
| Stuart and Binney, . | 15,319 | ,, | 24, ,, | Hydrocarbon and starting. |
| Taylor, . . . | 15,327 | ,, | 24, ,, | General design, valves and gear. |
| Southall, . . . | 15,472 | ,, | 26, ,, | Miscellaneous. |
| Wordsworth and Wolstenholme, | 15,507 | ,, | 27, ,, | Hydrocarbon. |
| ,, ,, | 15,507*a* | ,, | 27, ,, | ,, |
| Griffin, . . . | 15,764 | Dec. | 2, ,, | Shut off gas supply, automatic. |
| Hearson, . . . | 15,955 | ,, | 6, ,, | Utilising vapour. |
| Priestman and Priestman, . . | 16,779 | ,, | 21, ,, | Varying charges, hydrocarbon engine. |

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Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1887.

| | | | | Speciality. |
|---|---|---|---|---|
| Sterry, . . . . | 125 | Jan. | 4, 1887, | Varying stroke of gas engine. |
| Boulton and Perrett, . | 459 | ,, | 11, ,, | Steam and hot air. |
| Newall, . . . . | 516 | ,, | 12, ,, | Petroleum. |
| Lake, . . . . | 807 | ,, | 18, ,, | Hot air. |
| Abel, . . . . | 847 | ,, | 19, ,, | Ignition. |
| Hosack, . . . . | 888 | ,, | 20, ,, | Heat engine. |
| Charter, Galt, and Tracy, . . . | 1,168 | ,, | 25, ,, | Cylinders and pistons. |
| Abel, . . . . | 1,189 | ,, | 25, ,, | Quadruple cylinders. |
| Bénier, . . . . | 1,262 | ,, | 26, ,, | Hot air. |
| Adam, . . . . | 1,266 | ,, | 26, ,, | Petroleum. |
| Priestman and Priestman, . . | 1,454 | ,, | 29, ,, | Hydrocarburetted. |
| Lynam, . . . . | 1,683 | Feb. | 2, ,, | Heat engine. |
| Pinkney, . . . . | 1,986 | ,, | 2, ,, | Gas Hammer. |
| Haddan, . . . . | 2,194 | ,, | 11, ,, | Cylinders and electric ignition. |
| Bamford, . . . . | 2,236 | ,, | 12, ,, | Lubricants for gas engines. |
| Thomas, . . . . | 2,368 | ,, | 15, ,, | Pistons. |
| Jones, . . . . | 2,477 | ,, | 17, ,, | Hot air. |
| Browett and Lindley, . | 2,520 | ,, | 17, ,, | Electric ignition. |
| Tellier, . . . . | 2,631 | ,, | 19, ,, | Gas loco. |
| Knight, . . . . | 2,783 | ,, | 22, ,, | Hydrocarbon. |

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Koeber, . . . | 2,844 | Feb. | 24, | ,, | Caloric engine. |
| Spiel, . . . . | 3,109 | ,, | 28, | ,, | Hydrocarbon. |
| Griffin, . . . | 3,350 | March | 4, | 1887, | Pistons and stuffing boxes. |
| Redfern, . . . | 3,660 | ,, | 10, | ,, | Fluid pressure motor. |
| Schmidt, . . . | 3,705 | ,, | 11, | ,, | Compressed air and steam. |
| Griffin, . . . | 3,934 | ,, | 15, | ,, | Charges of mixtures. |
| Beechey, . . . | 4,160 | ,, | 19, | ,, | Gas bags to regulate supply. |
| Ross and M'Dowall, . | 4,403 | ,, | 24, | ,, | Rotatory engine and pumps. |
| Redealgh, . . . | 4,511 | ,, | 26, | ,, | Enclosed crank chamber. |
| Sington, . . . | 4,564 | ,, | 28, | ,, | Tram and vehicles. |
| Howard, Howard and Lloyd, . . . | 4,692 | ,, | 29, | ,, | Hot air. |
| Casper, . . . | 4,757 | ,, | 30, | ,, | Utilising heat after explosion. |
| Stevens, . . . | 4,843 | ,, | 31, | ,, | Combined gas and compressed air. |
| Sturgeon, . . . | 4,923 | April | 2, | ,, | Double piston, |
| Wallwork, . . . | 4,940 | ,, | 2, | ,, | Lubricating. |
| Johnson, . . . | 5,095 | ,, | 5, | ,, | Igniting. |
| Bernhardt, . . . | 5,336 | ,, | 12, | ,, | Regulating. |
| Hargreaves, . . | 5,485 | ,, | 15, | ,, | Thermodynamic engine. |
| Crossley, . . . | 5,833 | ,, | 21, | ,, | Combined gas and dynamo. |
| Priestman and Priestman, . . | 5,951 | ,, | 23, | ,, | Hydrocarbon and valves. |
| Koerting, . . . | 5,981 | ,, | 25, | ,, | Valves and governing. |
| Dawson, . . . | 6,501 | May | 3, | ,, | Cylinders, governing and igniting. |
| Faber, . . . | 7,350 | ,, | 20, | ,, | Cylinders, valves and ignition. |
| Davy, . . . . | 7,677 | ,, | 25, | ,, | Piston and twin gas engines. |
| Wastfield, . . . | 7,771 | ,, | 28, | ,, | Cylinder and valves. |
| Wallwork and Sturgeon, . . | 7,925 | June | 1, | ,, | Adjustable ports. |
| Johnson, . . . | 8,182 | ,, | 7, | ,, | Propelling by reaction of explosion. |
| Wastfield, . . . | 8,466 | ,, | 13, | ,, | Low pressure or vacuum motor. |
| Beechey, . . . | 8,818 | ,, | 18, | ,, | Cylinders and valves. |
| Lewis, . . . | 8,883 | ,, | 22, | ,, | Valves. |
| Haddan, . . . | 9,111 | ,, | 27, | ,, | Petroleum. |
| ,, . . . | 9,461 | July | 4, | ,, | Air engine. |
| Kühne, . . . | 9,506 | ,, | 5, | ,, | Hot air and motive power. |
| Duevettet, . . . | 9,717 | ,, | 11, | ,, | Oil for gas engine. |
| Hahn, . . . | 10,176 | ,, | 20, | ,, | Carburetter. |
| Bull and Bull, . . | 10,202 | ,, | 21, | ,, | Gas and steam. |
| Dougill, . . . | 10,360 | ,, | 25, | ,, | Piston, slides and governing. |
| Griffin, . . . | 10,460 | ,, | 27, | ,, | Twin engines. |
| Tennent, . . . | 11,201 | Aug. | 16, | ,, | Heating air. |
| Justice, . . . | 11,255 | ,, | 17, | ,, | General design, and electric ignition. |
| Lindley and Browett, . | 11,345 | ,, | 19, | ,, | Valves. |
| Abel, . . . . | 11,444 | ,, | 22, | ,, | Ignition. |
| Wordsworth, . . | 11,466 | ,, | 23, | ,, | Hydrocarbon. |
| Abel, . . . . | 11,503 | ,, | 23, | ,, | Cylinders and valves. |
| Niel and Bennett, . | 11,567 | ,, | 25, | ,, | Hydrocarbon. |
| Embleton, . . . | 11,717 | ,, | 29, | ,, | Cylinders and ignition. |
| Atkinson, . . . | 11,911 | Sept. | 2, | ,, | Varying expansion. |

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Abel, . . . . | 12,187 | Sept. | 8, | 1887, | Reservoir of gas and air. |
| Priestman and Priestman, . . | 12,432 | ,, | 13, | ,, | Hydrocarbon. |
| Lane, . . . . | 12,591 | ,, | 16, | ,, | Power to vehicles by compressed air. |
| Hearsons, . . . | 12,592 | ,, | 16, | ,, | Vaporising hydrocarbons. |
| List and others, . . | 12,696 | ,, | 19, | ,, | Petroleum motor. |
| Boult, . . . . | 12,749 | ,, | 20, | ,, | Oil and electric ignition. |
| M'Dowall, . . . | 12,758 | ,, | 20, | ,, | Sight feed lubricators for gas engine. |
| Koerting, . . . | 12,863 | ,, | 22, | ,, | Valves and ignition. |
| Lea, . . . . | 13,436 | Oct. | 4, | ,, | Starting gas engines. |
| Knight, . . . | 13,555 | ,, | 6, | ,, | Ignition for hydrocarbon engine. |
| Davy, . . . . | 13,916 | ,, | 13, | ,, | Supply to motors. |
| Barker, . . . | 14,027 | ,, | 15, | ,, | Admission and ignition. |
| Middleton, . . . | 14,048 | ,, | 17, | ,, | Varying stroke. |
| Hutchinson, . . . | 14,269 | ,, | 20, | ,, | Jackets for vaporising oil. |
| Schmidt and Beekfeld, | 14,952 | Nov. | 2, | ,, | Cylinders and valves. |
| Crossley and Anderson, | 15,010 | ,, | 3, | ,, | Ignition. |
| Butler, . . . | 15,598 | ,, | 15, | ,, | Hydrocarbon for vehicles. |
| Davy, . . . . | 15,658 | ,, | 15, | ,, | Oil jacketed cylinders. |
| Williams, . . . | 16,029 | ,, | 22, | ,, | Cylinders and pistons. |
| ,, . . . . | 16,144 | ,, | 24, | ,, | Cylinders and ignition. |
| Ravel and Brecttmayer, | 16,257 | ,, | 26, | ,, | Cylinders and valves. |
| Sturgeon, . . . | 16,309 | ,, | 28, | ,, | Cylinders and pistons. |
| Abel, . . . . | 17,108 | Dec. | 12, | ,, | Motor engine by gas, vapour, or spray. |
| Wallwork and Sturgeon, . . | 17,353 | ,, | 17, | ,, | Governing. |
| Bickerton, . . . | 17,686 | ,, | 23, | ,, | Starting by water motor. |
| Abel, . . . . | 17,896 | ,, | 29, | ,, | Ignition, tubes heated. |

## Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1888.

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Priestman and Priestman, . . | 270 | Jan. | 6, | ,, | Starting hydrocarbon engines. |
| Rogers, . . . . | 281 | ,, | 7, | ,, | Compressed air. |
| Sington, . . . . | 512 | ,, | 12, | ,, | Gas and petroleum. |
| Johnson, . . . . | 600 | ,, | 14, | ,, | Hot air. |
| Abel, . . . . | 688 | ,, | 16, | ,, | Igniting. |
| Imray, . . . . | 1,336 | ,, | 28, | ,, | Starting gas and tram engines. |
| Blessing, . . . | 1,381 | ,, | 30, | ,, | Hydrocarbon for tram engines. |
| Crossley, . . . | 1,705 | Feb. | 4, | ,, | Compound gas or oil motor. |
| Butler, . . . . | 1,780 | ,, | 6, | ,, | Hydrocarbon. |
| ,, . . . . | 1,781 | ,, | 6, | ,, | ,, |
| Quack, . . . . | 2,466 | ,, | 18, | ,, | Gas, vapour, or air. |
| Cole, . . . . | 2,467 | ,, | 18, | ,, | Cranks longer than cylinder, gas and other engines. |
| Windhausen, . . . | 2,549 | ,, | 21, | ,, | F |

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Johnson, . . . | 2,804 | Feb. | 24, | 1888, | Cylinders and valves for admission and exhaust. |
| ,, . . . | 2,805 | ,, | 24, | ,, | Starting gear. |
| Ochelhauser, . . | 2,913 | ,, | 27, | ,, | Rapid combustion in gas engine. |
| Abel, . . . . | 3,020 | ,, | 28, | ,, | Gas, vapour, or air. |
| ,, . . . . | 3,095 | ,, | 29, | ,, | Igniting gas or oil motor engine. |
| M'Ghee and Burt, . | 3,427 | March | 6, | ,, | Governing and sun and planet motion. |
| Rollason and Hamilton, . . | 3,546 | ,, | 7, | ,, | Starting, governing, and reservoir. |
| Crossley, . . . | 3,756 | ,, | 10, | ,, | Ignition and valves. |
| Gaze, . . . . | 3,964 | ,, | 14, | ,, | Compress gas and air and store separately. |
| Turner, . . . | 4,057 | ,, | 16, | ,, | Compressed air for motor. |
| Bourne, . . . | 4,531 | ,, | 24, | ,, | Hydrocarbon. |
| Crossley, . . . | 4,624 | ,, | 26, | ,, | Valves and governing gear. |
| Wilson, . . . | 4,944 | April | 3, | ,, | Gas engine and producer. |
| Lake, . . . . | 5,204 | ,, | 7, | ,, | Ignition for gas and petroleum. |
| Tavernier and Casper, | 5,628 | ,, | 16, | ,, | Gas and steam. |
| Humes, . . . | 5,632 | ,, | 16, | ,, | Hydrocarbon. |
| Abel, . . . . | 5,724 | ,, | 17, | ,, | Petroleum. |
| Rowden, . . . | 5,774 | ,, | 18, | ,, | Increased efficiency of gas, &c., engines. |
| Lake, . . . . | 5,914 | ,, | 20, | ,, | Hydrocarbon. |
| Gaze, . . . . | 6,036 | ,, | 23, | ,, | Compressing gas and air separately. |
| Thompson, . . . | 6,088 | ,, | 24, | ,, | Production of carburetted air. |
| Wells and others, . | 6,108 | ,, | 24, | ,, | Hot air motor. |
| Tellier, . . . | 6,212 | ,, | 26, | ,, | Producing cold by waste heat. |
| Karylynski, . . | 6,468 | May | 1, | ,, | Gas and air motor for vehicles. |
| Wordsworth, . . | 7,521 | ,, | 22, | ,, | Hydrocarbon. |
| Browett and Lindley, . | 7,547 | ,, | 22, | ,, | Valves for hydrocarbon engine. |
| Schnell, . . . | 7,893 | ,, | 30, | ,, | Hydrocarbon. |
| Stubbs, . . . | 7,927 | ,, | 30, | ,, | ,, |
| Southall, . . . | 7,934 | ,, | 30, | ,, | Cylinders, valves, and second shaft gas engine. |
| Nelson, . . . | 8,009 | June | 1, | ,, | Hydrocarbon and igniting. |
| Johnston, . . . | 8,252 | ,, | 6, | ,, | Cylinders and pistons, gas or vapour. |
| Kosztovito, . . | 8,273 | ,, | 6, | ,, | Cylinders for gas or hydrocarbon and locomotives. |
| De Boutteville and Malandin, . . | 8,300 | ,, | 6, | ,, | Starting. |
| Altman, . . . | 8,317 | ,, | 7, | ,, | Prevention of premature explosion in petroleum. |
| De Boutteville and Malandin, . . | 9,249 | ,, | 25, | ,, | Governor for gas and other engine. |
| Roots, . . . | 9,310 | ,, | 26, | ,, | Piston and second explosion chamber. |
| ,, . . . | 9,311 | ,, | 26, | ,, | Generator to hydrocarbon. |

| | | | | Speciality. |
|---|---|---|---|---|
| Dougill, | 9,578 | July | 2, 1888, | Timing motion of valve for admission, &c. |
| Abel, | 9,602 | ,, | 2, ,, | Valve for gas or hydrocarbon. |
| Knight, | 9,691 | ,, | 4, ,, | Hydrocarbon. |
| Rawden, | 9,705 | ,, | 4, ,, | Arrangement of cranks. |
| Purnell, | 10,165 | ,, | 12, ,, | General design. |
| Nash, | 10,350 | ,, | 17, ,, | General design and ignition. |
| Giffard, | 10,645 | ,, | 23, ,, | Compressed air motor. |
| Binney and Stuart, | 10,667 | ,, | 24, ,, | Hydrocarbon. |
| Campbell, | 10,748 | ,, | 25, ,, | General design. |
| Hargreaves, | 10,980 | ,, | 30, ,, | Combustion thermomotor. |
| Piers, | 10,983 | ,, | 30, ,, | Hot air, compressed do., and gas for tram loco. |
| ,, | 10,984 | ,, | 30, ,, | Starting tram loco., with air, gas, &c. |
| Roots, | 11,067 | ,, | 31, ,, | Hydrocarbon. |
| Morris and Wilson, | 11,161 | Aug. | 1, ,, | Generator for gas and hydrocarbon. |
| Barker, | 11,242 | ,, | 3, ,, | Valves and governing. |
| Purchas and Freund, | 11,614 | ,, | 11, ,, | Hydrocarbon. |
| Ellis, | 11,847 | ,, | 16, ,, | Hot air, gas, or steam. |
| Hargreaves, | 12,361 | ,, | 28, ,, | Thermomotors. |
| Charon, | 12,399 | ,, | 28, ,, | Variable expansion and igniting. |
| Wells, | 13,206 | Sept. | 12, ,, | Hot air. |
| Boult, | 13,414 | ,, | 17, ,, | Cylinders, pistons, valves, and cranks. |
| Stuart and Binney, | 14,076 | Oct. | 1, ,, | Hydrocarbon. |
| Crossley and Holt, | 14,248 | ,, | 3, ,, | Starting. |
| Abel, | 14,349 | ,, | 5, ,, | Ignition, gas or oil. |
| Hearsons, | 14,401 | ,, | 6, ,, | Charging and ejection of spent charges. |
| Royston, | 14,614 | ,, | 11, ,, | Heat engine. |
| Williams, | 14,831 | ,, | 16, ,, | Governing. |
| Richards, | 15,158 | ,, | 22, ,, | Hydrocarbon. |
| Thompson, | 15,448 | ,, | 27, ,, | Carburetter to gas engine. |
| Boult, | 15,840 | Nov. | 2, ,, | Petroleum. |
| ,, | 15,841 | ,, | 2, ,, | Ignition. |
| ,, | 15,845 | ,, | 2, ,, | Keeping walls cool. |
| ,, | 15,846 | ,, | 2, ,, | Friction clutch for gas engines. |
| Jensen, | 15,858 | ,, | 2, ,, | Braking and restarting. |
| Roots, | 15,882 | ,, | 3, ,, | Starting petroleum engine. |
| Lindley and Browett, | 16,057 | ,, | 6, ,, | Hydrocarbon. |
| Simon, | 16,183 | ,, | 8, ,, | Cylinder and piston. |
| Roots, | 16,220 | ,, | 9, ,, | Governing and starting. |
| Lalbin, | 16,268 | ,, | 9, ,, | Multiple cylinder and ignition. |
| Menzies, | 16,605 | ,, | 15, ,, | Piston rings. |
| Koerting, | 17,167 | ,, | 26, ,, | Valve for gas or petroleum. |
| Schmidt, | 17,343 | ,, | 28, ,, | Steam and air. |
| Crossley and Anderson, | 17,413 | ,, | 28, ,, | Ignition, oil or gas. |
| Shaw, | 18,377 | Dec. | 17, ,, | General design. |
| Davies, | 18,516 | ,, | 18, ,, | Utilising waste heat of gas engine. |
| Nichols, | 18,707 | ,, | 21, ,, | Obtaining variable speed. |
| Hargreaves, | 18,761 | ,, | 22, ,, | Thermomotor. |
| Pinkney, | 19,013 | ,, | 29, ,, | General design. |

## Specification of Patents filed for Gas, Petroleum, &c., Engines for the Year 1889.

| | | | | Speciality. |
|---|---|---|---|---|
| Boult, . . . . | 121 | Jan. | 3, 1889, | Distributing mechanism. |
| Robinson, . . . . | 298 | ,, | 8, ,, | Hot air. |
| Paton, . . . . | 441 | ,, | 10, ,, | Starting. |
| Taylor, . . . . | 708 | ,, | 15, ,, | Double cylinder, and general design. |
| Repland, . . . . | 875 | ,, | 17, ,, | Second cylinder for charge, greater volume. |
| Wells, . . . . | 1,593 | ,, | 29, ,, | Hot air, combination cylinder and chamber. |
| Tavernier and Schlesinger, . . | 1,603 | ,, | 29, ,, | Hydrocarbon, jacketed cylinder. |
| Thompson, . . . | 1,831 | Feb. | 1, ,, | Slide valves for gas engines. |
| Peebles, . . . . | 1,957 | ,, | 4, ,, | Double-acting gas engine. |
| Ketchem, . . . . | 1,977 | ,, | 4, ,, | Generation of steam and gases. |
| Field, . . . . . | 1,997 | ,, | 4, ,, | Hot air and gases. |
| Piers, . . . . . | 2,144 | ,, | 6, ,, | Locomotion by gas or petroleum. |
| Davenport and Horsley, . . . | 2,587 | ,, | 14, ,, | Pistons for gas engines. |
| Miller, . . . . | 2,637 | ,, | 14, ,, | Petroleum vapour or gas, general design. |
| Gardie, . . . . | 2,649 | ,, | 14, ,, | Gas engine and generator. |
| Adams, . . . . | 3,331 | ,, | 25, ,, | Explosion reservoir. |
| Pinkney, . . . . | 3,525 | ,, | 27, ,, | Working gear of gas engines. |
| Williams, . . . . | 3,820 | March | 5, ,, | Double-acting gas engines. |
| Roots, . . . . | 3,972 | ,, | 6, ,, | General improvements. |
| Schmidt, . . . . | 4,237 | ,, | 11, ,, | Mixed steam and gas motors. |
| Phillips, . . . . | 4,302 | ,, | 12, ,, | Hot air. |
| Von Ochelhauser, . | 4,710 | ,, | 18, ,, | Ignition of variable mixture of gas. |
| Schemmings, . . . | 4,796 | ,, | 19, ,, | Superheating steam, by inflammable gas. |
| Southall, . . . . | 5,072 | ,, | 23, ,, | Oil or gas combination, reservoir and cylinder. |
| Lake, . . . . . | 5,165 | ,, | 26, ,, | Propulsion of vessel by explosion engine. |
| Millet, . . . . | 5,199 | ,, | 26, ,, | Propulsion of vehicles and aerial do. by gas engine. |
| Theevman, . . . . | 5,301 | ,, | 28, ,, | Charging cylinder, gas, vapour and hydrocarbon. |
| Nelson and M'Millan, . | 5,397 | ,, | 29, ,, | Valves and governing. |
| Abel, . . . . . | 5,616 | April | 2, ,, | Reversing mechanism. |
| Bánki and Csonki, . | 6,296 | ,, | 12, ,, | Valve motion. |
| Priestman and Priestman, . . | 6,682 | ,, | 18, ,, | Hydrocarbon. |
| Cordenons, . . . | 6,748 | ,, | 20, ,, | Rotatory gas, petroleum, or steam. |
| Knight, . . . . | 6,831 | ,, | 24, ,, | Vaporiser for engines by oil. |

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Tavernier and Casper, | 7,069 | April, | 27, | 1889, | Cooling, cylinder of gas engine. |
| Tellier, . . . | 7,140 | ,, | 29, | ,, | Producing combustible gases for power. |
| Sumner, . . . | 7,522 | May | 6, | ,, | Ignition by electricity. |
| ,, . . . | 7,533 | ,, | 6, | ,, | Ignition by incandescent platinum. |
| Crowe and Crowe, . | 7,594 | ,, | 7, | ,, | Gas or hydrocarbon, general design. |
| Sergeant, . . . | 7,605 | ,, | 7, | ,, | Valves for steam and air engines. |
| Lawson, . . . | 7,640 | ,, | 7, | ,, | General design. |
| Weatherhogg, . . | 8,013 | ,, | 14, | ,, | Petroleum and general design. |
| Imray, . . . | 8,778 | ,, | 27, | ,, | Supplying petroleum to engines. |
| Clerk, . . . | 8,805 | ,, | 28, | ,, | Double piston for gas engines. |
| Lake, . . . . | 8,886 | ,, | 28, | ,, | Hot air. |
| Butler, . . . | 9,203 | June | 3, | ,, | Multiple cylinder, Petroleum. |
| Hunt and Howden, . | 9,685 | ,, | 12, | ,, | Reaction wheel, by combustible gas or vapour. |
| Roots, . . . | 9,834 | ,, | 15, | ,, | Hydrocarbon. |
| Daimler, . . . | 10,007 | ,, | 18, | ,, | Gas and petroleum motors. |
| Wells and Clarke, . | 10,144 | ,, | 21, | ,, | Hot air. |
| Rogers and Wharry, . | 10,286 | ,, | 24, | ,, | General design. |
| Bull, . . . . | 10,634 | July | 1, | ,, | Petroleum or other explosive generator. |
| Rowden, . . . | 10,669 | ,, | 2, | ,, | Link connection for gas engines. |
| Leigh, . . . | 10,831 | ,, | 5, | ,, | Compound gas or petroleum. |
| Wastfield, . . . | 10,850 | ,, | 5, | ,, | Petroleum or other hydrocarbon. |
| White and Raphael, . | 11,038 | ,, | 9, | ,, | General design. |
| Williams, . . . | 11,162 | ,, | 11, | ,, | Tube for igniting. |
| Hartley, . . . | 11,395 | ,, | 16, | ,, | Hydrocarbon vaporiser and air heater. |
| Dheyne, . . . | 11,459 | ,, | 17, | ,, | Generating gas from combustible liquid. |
| Bull, . . . . | 11,926 | ,, | 26, | ,, | Admission passages and valves for gas, air, or vapour. |
| Allison, . . . | 12,045 | ,, | 30, | ,, | Combined carburetter and gas engine. |
| Hoelljes, . . . | 12,447 | Aug. | 6, | ,, | Methods of operating gas engines. |
| Thompson, . . . | 12,472 | ,, | 7, | ,, | Combination of cylinder and pumps. |
| Lanchester, . . | 12,502 | ,, | 7, | ,, | Governing, gas and other motive power. |
| Middleton, . . . | 13,431 | ,, | 26, | ,, | Gas and steam power tricycle. |
| M'Allen, . . . | 13,572 | ,, | 28, | ,, | Gas or oil motor. |
| Bennett, . . . | 14,154 | Sept. | 7, | ,, | Motive power from carbonic oxide. |
| Huntington, . . | 14,592 | ,, | 17, | ,, | Vehicles, by vapour engines. |
| Hargreaves, . . | 14,789 | ,, | 19, | ,, | Thermomotor. |

| | | | | Speciality. |
|---|---|---|---|---|
| Binney and Stuart, | 14,868 | Sept. | 20, 1889, | Hydrocarbon. |
| Diederichs, | 14,926 | ,, | 21, ,, | Combustible vapour engine. |
| Willcox, | 14,927 | ,, | 21, ,, | Hot air. |
| M'Tighe, | 15,805 | ,, | 24, ,, | Conversion of heat into motive power. |
| Spurway, | 15,295 | ,, | 28, ,, | Hot air and other gas. |
| Green, | 16,202 | Oct. | 15, ,, | General arrangement. |
| Lindemann, | 16,391 | ,, | 17, ,, | Valve arrangement. |
| Hamilton and Rollason, | 16,434 | ,, | 18, ,, | Gas or vapour, general design. |
| Haedicke, | 17,008 | ,, | 28, ,, | Combined gas, and steam engine. |
| Boult, | 17,024 | ,, | 28, ,, | Petroleum. |
| Niel, | 17,295 | ,, | 31, ,, | Valves, ports, governing and lubricating. |
| Lowne, | 17,344 | Nov. | 1, ,, | Atmospheric engine. |
| Abel, | 18,746 | ,, | 22, ,, | Igniting gas or oil motor engine. |
| Schmidt, | 18,813 | ,, | 23, ,, | Steam and air motors. |
| Barrett and Daly, | 18,847 | ,, | 23, ,, | Electric igniter. |
| Schmidt, | 19,124 | ,, | 28, ,, | Combined steam and hot air. |
| Lanchester, | 19,868 | Dec. | 10, ,, | Valves and governing. |
| Lindley and Browett, | 20,033 | ,, | 12, ,, | Hydrocarbon. |
| Ford, | 20,115 | ,, | 13, ,, | Rotatory gas engine. |
| Duerr, | 20,161 | ,, | 14, ,, | Gas or petroleum motor. |
| Frederking and Schubert, | 20,166 | ,, | 14, ,, | Valve gear for gas, steam, &c. |
| Crist and Covert, | 20,249 | ,, | 17, ,, | Igniters and general design. |
| Atkinson, | 20,482 | ,, | 20, ,, | Internal combustion heat engine. |
| Clark, | 20,512 | ,, | 20, ,, | Throttle valve for gas and other engines. |
| Snelling, | 20,703 | ,, | 24, ,, | Rotatory gas, steam, or air engine. |
| Jenks, | 20,748 | ,, | 24, ,, | Governors for gas and other engines. |
| Abel, | 20,892 | ,, | 30, ,, | Regulating speed of gas or oil motors. |

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### Specification of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1890.

| | | | | Speciality. |
|---|---|---|---|---|
| Mewburn, | 132 | Jan. | 3, 1890, | Air motor. |
| Mannesman, | 837 | ,, | 16, ,, | Compressed air and combustible fluid. |
| Bedford and Rodger, | 1,064 | ,, | 21, ,, | Metallic packing. |
| Linder, | 1,150 | ,, | 22, ,, | Petroleum, general design. |
| Tavernier, | 1,586 | ,, | 29, ,, | Cylinders and pistons. |
| Abel, | 1,943 | Feb. | 5, ,, | Petroleum, general design. |
| Scollary, | 2,207 | ,, | 11, ,, | Regulating gas supply. |

| | | | | Speciality. |
|---|---|---|---|---|
| Touche, . . . | 2,384 | Feb. | 13, 1890, | Petroleum igniting by liquid petroleum. |
| Lake, . . . | 2,647 | ,, | 18, ,, | Combination of cylinders. |
| ,, . . . | 2,648 | ,, | 18, ,, | Air engine. |
| Grob and others, | 2,914 | ,, | 24, ,, | Petroleum motor, air to inlets. |
| Munden, . . . | 3,128 | ,, | 27, ,, | Speed varying gear. |
| Abel, . . . | 4,164 | March | 17, ,, | Governing, gas and petroleum. |
| Binns, . . . | 4,362 | ,, | 20, ,, | Additional cylinders, pistons, and ignition. |
| Kaselowsky, . . | 4,574 | ,, | 24, ,, | Petroleum and gas, inlets and ignition. |
| Otto, . . . | 4,823 | ,, | 27, ,, | General improvement for regular working. |
| Baxter, . . . | 5,005 | ,, | 31, ,, | Gradual mixture outside cylinder. |
| Meluish, . . . | 5,192 | April | 3, ,, | Gas and petroleum, compound engine. |
| Otto, . . . | 5,273 | ,, | 5, ,, | Regulating gas or oil motors. |
| ,, . . . | 5,275 | ,, | 5, ,, | Mixture of atmospheric air and of oil. |
| Lanchester, . . | 5,479 | ,, | 10, ,, | Starting. |
| Mayer, . . . | 5,787 | ,, | 16, ,, | Cylinders and pistons. |
| Dheyne and others, | 5,933 | ,, | 18, ,, | Petroleum and gas, general design. |
| Otto, . . . | 5,972 | ,, | 19, ,, | Ignition and regulating. |
| Hamilton, . . | 6,015 | ,, | 21, ,, | Gas or vapour motor, general design. |
| Otto, . . . | 6,113 | ,, | 22, ,, | Supplementary cylinder, piston, and valve. |
| Griffin, . . . | 6,217 | ,, | 23, ,, | Combustible gases for motors. |
| Dawson, . . . | 6,407 | ,, | 26, ,, | Reciprocating and rotatory, *no valves*. |
| Donington, . . | 6,910 | May | 5, ,, | Double cylinders, position and angle of. |
| Fielding, . . . | 6,912 | ,, | 5, ,, | General design. |
| Butler, . . . | 6,990 | ,, | 6, ,, | Hydrocarbon, general design. |
| Stuart and Binney, | 7,146 | ,, | 8, ,, | Vaporiser direct to cylinder. |
| Mewburn, . . | 7,177 | ,, | 8, ,, | Combined gas and compressed air motor. |
| Johnson, . . . | 7,626 | ,, | 16, ,, | Engine, sector of sphere, and separate chamber for combustion, &c. |
| Sykes and Blamiris, | 7,830 | ,, | 20, ,, | Conversion of solid into gaseous fuel. |
| Popp, . . . | 8,322 | ,, | 29, ,, | Compressed air motor and heating stove thereof. |
| Seage and Seage, | 8,431 | ,, | 31, ,, | Lever, gear for valves. |
| Robson, . . . | 9,496 | June | 19, ,, | Double pistons, unequal strokes. |
| Butterfield, . . | 9,769 | ,, | 24, ,, | Lubricators. |
| Wilkinson, . . | 10,051 | ,, | 28, ,, | Producing carburetted air for motors. |
| Beechey, . . . | 10,089 | ,, | 30, ,, | Piston valves. |

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Williams, . . . | 10,137 | July | 1, | 1890, | Obtaining motive power by explosion. |
| Stuart, . . . | 10,293 | ,, | 3, | ,, | Obtaining power from ammonia and compressed air. |
| Vogelsang and Hille, . | 10,642 | ,, | 9, | ,, | Valve gear for petroleum and gas engines. |
| Grob, Shutze, and others, . . . | 10,718 | ,, | 10, | ,, | Ignition of gas, petroleum, and vapour engines. |
| Griffin, . . . | 10,952 | ,, | 14, | ,, | Valves for regulating and governing. |
| Lake, . . . . | 11,062 | ,, | 15, | ,, | Hydrocarbon, general design. |
| Wells and others, . | 11,174 | ,, | 17, | ,, | Recovery of heat from steam and hot air. |
| Richardson and Norris, | 11,755 | ,, | 28, | ,, | Ignition and other valves for gas or vapour. |
| Schiersand, . . | 11,834 | ,, | 29, | ,, | Governor. |
| Pollitt, . . . | 12,111 | Aug. | 2, | ,, | Converting heat into mechanical energy. |
| Holt, . . . . | 12,314 | ,, | 6, | ,, | Supply, exhaust, and governing oil motors. |
| Stuart, . . . | 12,472 | ,, | 9, | ,, | Compound, hydrocarbon, & reciprocating cylinder. |
| M'Ghee and Burt, . | 12,690 | ,, | | ,, | Collapsible reservoir, governing and igniting. |
| Justice, . . . | 12,678 | ,, | 13, | ,, | Motor, general, for road and tram cars. |
| Stallairt, . . . | 12,760 | ,, | 14, | ,, | Charging device, fulminate for ignition. |
| Vermand, . . . | 13,019 | ,, | 19, | ,, | Compression of air in special cylinder. |
| Stuart, . . . | 13,051 | ,, | 20, | ,, | Rotatory engine. |
| Ovens and Ovens, . | 13,352 | ,, | 25, | ,, | Ignition, valves, and cooling. |
| Offen, . . . . | 13,594 | ,, | 29, | ,, | Combination of cylinders and pistons. |
| Hall, . . . . | 14,382 | Sept. | 12, | ,, | Ignition. |
| Roots, . . . | 14,549 | ,, | 16, | ,, | Double explosion, second explosion chamber. |
| Robinson, . . . | 14,787 | ,, | 19, | ,, | Operating, valves. |
| De Boutteville and Malandin, . . | 14,900 | ,, | 20, | ,, | Governing, regulating, and valves. |
| Redfern, . . . | 15,063 | ,, | 23, | ,, | Hot air, high pressure. |
| Hartley, . . . | 15,309 | ,, | 27, | ,, | Hydrocarbon vaporiser. |
| Vivian, . . . | 15,479 | ,, | 30, | ,, | Hot air, general design. |
| Dheyne and others, . | 15,525 | Oct. | 1, | ,, | Copper and nickel, coils in connection with gas, &c., engines. |
| ,, ,, . | 15,526 | ,, | 1, | ,, | Conversion of liquid hydrocarbon into gas. |
| Campion and Woods, . | 15,807 | ,, | 6, | ,, | Utilisation and combustion of hydrocarbon gases. |
| Stuart and Binney, . | 15,994 | ,, | 8, | ,, | Chamber highly heated for ignition. |
| Cruickshank, . . | 16,301 | ,, | 14, | ,, | General design. |
| Pinkney, . . . | 17,167 | ,, | 27, | ,, | Gas or petroleum, general design. |

| | | | | Speciality. |
|---|---|---|---|---|
| Mattershead, | 17,299 | Oct. | 29, 1890, | Compound cylinder, hollow valves, combining passages and ignition, &c. |
| Higginson, | 17,371 | ,, | 30, ,, | Loose piston controlled by compressed air. |
| Sayer, | 18,161 | Nov. | 11, ,, | Gaseous pressure, apparatus for producing motion. |
| Griffin, | 18,401 | ,, | 14, ,, | Igniting in hydrocarbon or petroleum. |
| Boult, | 18,645 | ,, | 18, ,, | Governors. |
| Kaselowsky, | 19,171 | ,, | 25, ,, | Igniting devices. |
| Lanchester, | 19,513 | Dec. | 1, ,, | Ignition and starting, gas or hydrocarbon. |
| Roots, | 19,559 | ,, | 1, ,, | Prevention of leakage in petroleum, &c. |
| Lobet, | 19,791 | ,, | 4, ,, | Distributing device for valves. |
| Griffin, | 19,962 | ,, | 6, ,, | Forming combustible spray of air and finely divided hydrocarbon. |
| Albrecht, | 20,226 | ,, | 11, ,, | Gas generator and motor combined. |
| Holt, | 20,888 | ,, | 22, ,, | Water jacket and tank for uniform temperature. |
| Lentz and others, | 21,165 | ,, | 29, ,, | Single acting engine, general design (novel). |

## Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1891.

| | | | | Speciality. |
|---|---|---|---|---|
| Pinkney, | 103 | Jan. | 2, 1891, | Position of valves, and ignition, hydrocarbon. |
| Carling, | 110 | ,, | 3, ,, | Governing gas and other engines. |
| Gray, | 191 | ,, | 5, ,, | Producing explosive mixture, hydrocarbon. |
| Bickerton, | 227 | ,, | 6, ,, | Prevention of noise by intake of air. |
| Bickerton, | 297 | ,, | 7, ,, | Governing. |
| Boult, | 383 | ,, | 8, ,, | Valve gear for gas or petroleum. |
| Kehlberger and Fougue, | 458 | ,, | 9, ,, | Areo-hydro-thermo engine. |
| Adams, | 741 | ,, | 15, ,, | Rotatory engine. |
| MacCallum, | 816 | ,, | 16, ,, | Heat engine fluid piston. |
| Miller, | 834 | ,, | 16, ,, | Petroleum vaporiser and cylinder combined. |
| Williams, | 970 | ,, | 20, ,, | Combination of cylinder, piston and valves. |
| Robinson, | 1,083 | ,, | 21, ,, | Governing. |
| Williams, | 1,299 | ,, | 24, ,, | Timing opening, &c., of ig- |

| | | | | Speciality. |
|---|---|---|---|---|
| Weatherhogg, . . | 1,447 | Jan. | 27, 1891, | Hydrocarbon vaporiser. |
| Abel, . . . . . | 1,903 | Feb. | 2, ,, | Valves for gas and petroleum engines. |
| Gray, . . . . . | 2,053 | ,, | 4, ,, | Vaporiser for hydrocarbon. |
| Rouzay, . . . . | 2,815 | ,, | 16, ,, | Gas and petroleum, general design. |
| Hughes, . . . . | 2,976 | ,, | 18, ,, | Rotatory, three cylinders rotate. |
| Weiss, . . . . | 3,261 | ,, | 23, ,, | Production of combustible vapour from petroleum, &c. |
| Coffey, . . . . | 3,350 | ,, | 24, ,, | General design. |
| Rockhill, . . . . | 3,669 | ,, | 28, ,, | Flywheel guards for gas engines. |
| Wertenbrach, . . | 3,682 | ,, | 28, ,, | Pistons, double movable rings. |
| Priestman and Priestman, . . | 3,830 | March | 3, ,, | Admission of cold air to heated charge. |
| Trewhella, . . . | 3,948 | ,, | 5, ,, | Utilising residue of gases exploded. |
| Dawes, . . . . | 4,004 | ,, | 6, ,, | Starting. |
| Fenby, . . . . | 4,024 | ,, | 6, ,, | Valves for hydro and fluid pressure machines. |
| Priestman and Priestman, . . | 4,142 | ,, | 7, ,, | Hydrocarbon separating jacket into two parts. |
| Lanchester, . . . | 4,222 | ,, | 10, ,, | Governing by use of magnet. |
| Campbell, . . . | 4,355 | ,, | 11, ,, | Distributing combustible mixture. |
| Griffin, . . . . | 4,535 | ,, | 13, ,, | Regulating and governing. |
| Cooper, . . . . | 4,771 | ,, | 17, ,, | Ignition. |
| Vanduzen, . . . | 5,158 | ,, | 23, ,, | Gas and gasoline engine, general design. |
| Love and Priestman, . | 5,250 | ,, | 24, ,, | Using liquefiable gas for cooling jackets. |
| Higginson, . . . | 5,490 | ,, | 28, ,, | Treble cylinder. |
| Fachris, . . . . | 5,663 | April | 1, ,, | Explosive engine, by powder, "Gatling" system. |
| Skene, . . . . | 5,747 | ,, | 3, ,, | Anti-fluctuator and regulator for gas, &c. |
| Bickerton, . . . | 6,090 | ,, | 9, ,, | Igniting and starting. |
| Day, . . . . . | 6,410 | ,, | 14, ,, | Enclosed crank, and impulse every revolution. |
| Barclay, . . . . | 6,578 | ,, | 16, ,, | Double-acting, cylinder closed each end. |
| Ridealgh and Welford, | 6,598 | ,, | 17, ,, | Simple gas engine, general design. |
| Abel, . . . . . | 6,717 | ,, | 18, ,, | Supplying oil, &c., at constant pressure. |
| Rennes, . . , . | 6,727 | ,, | 18, ,, | Petroleum motor, for road cars, &c., |
| Key, . . . . . | 6,949 | ,, | 22, ,, | Discharge of gases. |
| Purnell, . . . . | 7,047 | ,, | 23, ,, | Governor for gas or oil motor. |
| Altman, . . . . | 7,157 | ,, | 25, ,, | ,, ,, |
| Pinkney, . . . . | 7,313 | ,, | 28, ,, | Conical combustion, chamber and ignition. |

| | | | | Speciality. |
|---|---|---|---|---|
| Horn, . . . . | 8,032 | May | 9, 1891, | Simple gas engine, general design. |
| Capitaine, . . . | 8,069 | ,, | 11, ,, | Combination of valves to inlet. |
| Barrett and Ticehurst, | 8,251 | ,, | 14, ,, | Starting gas engine by cartridges of explosives. |
| Hardingham, . . | 8,289 | ,, | 14, ,, | Rotatory gas engine. |
| Abel, . . . . | 8,469 | ,, | 16, ,, | Drawing in and expelling air for expansion. |
| Shillito, . . . | 8,821 | ,, | 25, ,, | Igniting tube for petroleum motors. |
| Boult, . . . | 9,006 | ,, | 27, ,, | Improved gas or petroleum engine, general design. |
| Southall, . . . | 9,038 | ,, | 28, ,, | Valves for charging, &c., |
| Day, . . . . | 9,247 | June | 1, ,, | Simple gas engine, run either way. |
| Bosshardt, . . . | 9,268 | ,, | 2, ,, | Governors and valves. |
| Huesler, . . . | 9,323 | ,, | 2, ,, | Gasifying contrivance for petroleum motors. |
| Hawkins, . . . | 9,805 | ,, | 10, ,, | Vibrating gas engine. |
| Withers and Covert, . | 9,931 | ,, | 11, ,, | ,, ,, |
| Crossley and Holt, | 10,298 | ,, | 17, ,, | Regulating supply of oil to oil motors. |
| Fiddes and Fiddes, | 10,333 | ,, | 18, ,, | Second piston at back end. |
| Irgens, . . | 11,132 | ,, | 30, ,, | Petroleum and gas motor and producer. |
| Pinkney, . . | 11,138 | ,, | 30, ,, | Petroleum combustion and igniting chamber. |
| Held, . . . . | 11,628 | July | 8, ,, | Gas pressure regulator for engines. |
| Kaselowsky, . | 11,680 | ,, | 9, ,, | Valve motion, petroleum engine, and generator. |
| Wellington, . | 11,851 | ,, | 13, ,, | Imperishable igniting tube. |
| Lanchester, . | 11,861 | ,, | 13, ,, | Starting gas motors. |
| Settle, . . | 12,330 | ,, | 21, ,, | Boat or tram propulsion by gas. |
| Clerk, . . . | 12,413 | ,, | 22, ,, | Operating valves. |
| Menard, . . | 12,981 | ,, | 31, ,, | Firing charges by magnetism, dynamo, and Rhumkorff coil. |
| ,, . . . | 12,981 | ,, | 31, ,, | ... |
| King, . . . | 14,002 | Aug. | 19, ,, | Cylinders, pistons, igniting and exhausting mechanism. |
| Weyman and Drohe, . | 14,133 | ,, | 21, ,, | Regulating supply of oil to hydrocarbon. |
| Watkinson, . | 14,134 | ,, | 21, ,, | Improvement in thermo-dynamo machine for gas, &c., motors. |
| Huelser, . . | 14,269 | ,, | 24, ,, | Link motion for opening valves. |
| Abel, . . . | 14,519 | ,, | 27, ,, | Igniting apparatus for oil or gas. |
| Hoffman, . . | 14,865 | Sept. | 2, ,, | Hot air, general design. |
| Lanchester, . | 14,945 | ,, | 4, ,, | Governors. |
| Williams, . . | 15,078 | ,, | 7, ,, | Starting. |
| Clerk, . . . | 16,404 | ,, | 28, ,, | Valve details. |
| Hornsby and Edwards, | 17,073 | Oct. | 7, ,, | Mixing hydrocarbon with air, petroleum motor. |

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Evers, . . . | 17,364 | Oct. | 12, | 1891. | Automatic valves. |
| Abel, . . . . | 17,724 | ,, | 16, | ,, | Valve apparatus controlling charges, &c. |
| Evans, . . . | 17,815 | ,, | 17, | ,, | Simple gas engine, rotatory valve. |
| Pinkney, . . . | 17,955 | ,, | 20, | ,, | Igniter for gas or petroleum engine. |
| Shaw and Asworth, | 18,020 | ,, | 21, | ,, | Better utilisation of pressure in gas engines. |
| Walch, Darrington, and others, . . . | 18,276 | ,, | 24, | ,, | Valve gear. |
| Field, . . . . | 18,503 | ,, | 27, | ,, | Improvement of engine worked by hot gases, such as air, &c. |
| Roots, . . . | 18,621 | ,, | 29, | ,, | Valve gear for internal combustion engine. |
| Weyman and others, . | 18,640 | ,, | 29, | ,, | Prevention of overheating in gas engines. |
| Earnshaw and others, | 18,715 | ,, | 30, | ,, | Valves of gas engines. |
| Clerk, . . . . | 18,788 | ,, | 31, | ,, | Starting gear. |
| Roots, . . . | 19,275 | Nov. | 7, | ,, | Improvement in hydrocarbon, &c., engines. |
| Barron, . . . | 19,318 | ,, | 9, | ,, | Conversion of slide gas engines to tube igniters. |
| Fielding, . . . | 19,517 | ,, | 11, | ,, | Starting. |
| Johnson, . . . | 19,772 | ,, | 14, | ,, | Feed pumps for petroleum engine. |
| ,, . . . | 19,773 | ,, | 14, | ,, | Means to regulate temperature of evaporation in petroleum engine. |
| Ridealgh, . . . | 19,811 | ,, | 16, | ,, | Sealed chamber and flexible partition in gas or petroleum motors. |
| Robinson, . . . | 20,262 | ,, | 21, | ,, | Gas engine, general design. |
| ,, . . . | 20,745 | ,, | 28, | ,, | Gas engine, cooling. |
| Perrollaz, . . . | 20,845 | ,, | 30, | ,, | Lubricators for gas engine. |
| Knight, . . . | 20,926 | Dec. | 1, | ,, | Vaporiser for petroleum and heavy hydrocarbons. |
| Weyman and others, . | 21,015 | ,, | 2, | ,, | Ignition, cooling, and vaporiser for hydrocarbon. |
| Lanchester, . . | 21,406 | ,, | 8, | ,, | Operating valves and governing. |
| Hartley and Kerr, | 21,496 | ,, | 9, | ,, | Governing gas engine. |
| Miller, . . . | 21,529 | ,, | 9, | ,, | Valve gear, specially exhaust. |
| Leigh, . . . | 22,559 | ,, | 24, | ,, | Utilisation of gases before expelled from cylinder. |
| ,, . . . | 22,559 | ,, | 24, | ,, | ,, ,, |
| Burt, . . . . | 22,578 | ,, | 28, | ,, | Starting, stopping, and reversing gas and vapour engines. |
| Seck, . . . . | 22,834 | ,, | 31, | ,, | Simple gas or hydrocarbon engine. |
| Abel, . . . . | 22,847 | ,, | 31, | ,, | Combination of vaporiser and explosion chamber of hydrocarbon and oil motors. |

## Specifications of Patents filed for Gas, Petroleum, and Hot Air Engines for the Year 1892.

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Richardson and Norris, | 112 | Jan. | 4, | 1892, | Starting gas and vapour engines. |
| Edwards, . . . | 260 | ,, | 6, | ,, | Heating uniformly mixtures of air and gas. |
| Krank, . . . | 435 | ,, | 8, | ,, | Utilisation of air or other gas for power. |
| Higginson, . . . | 520 | ,, | 11, | ,, | Double piston explosion between. |
| Wilkinson, . . . | 524 | ,, | 11, | ,, | Mixing vapour of benzoline with coal gas. |
| Rankin and Rankin, . | 826 | ,, | 15, | ,, | Hydrocarbon mixing and vaporising. |
| Simon, . . . | 926 | ,, | 16, | ,, | Starting gas or petroleum engines. |
| Thompson, . . . | 1,075 | ,, | 19, | ,, | Controlling power of engine. |
| Southall, . . . | 1,203 | ,, | 21, | ,, | Discharge valve for gas or oil motor. |
| Brooks and Holt, . | 1,246 | ,, | 22, | ,, | Water jacket of gas and vapour engine. |
| Richardson and Norris, | 1,768 | ,, | 29, | ,, | Valve and operating valves of gas and vapour engine. |
| Schwarz, . . . | 1,814 | ,, | 29, | ,, | Starting and storing power. |
| Barker, . . . | 1,879 | Feb. | 1, | ,, | Gas bags for gas engines. |
| Atkinson, . . . | 2,181 | ,, | 4, | ,, | Self starting gas and vapour engine. |
| ,, . . . | 2,492 | ,, | 9, | ,, | Internal combustion engine, general design. |
| Swiderski, . . . | 2,495 | ,, | 9, | ,, | Distribution of inflammable vapour and air. |
| Abel, . . . . | 2,728 | ,, | 11, | ,, | Operating valves for regulating gas and oil motors. |
| Leigh, . . . | 2,854 | ,, | 13, | ,, | Supplying liquid hydrocarbon, igniting, and governing. |
| Crossley and Bradley, | 2,862 | ,, | 13, | ,, | Starting and igniting gas or oil motors. |
| Jonstone, . . . | 3,047 | ,, | 16, | ,, | Oscillating cylinder, gas or oil. |
| Harris, . . . | 3,165 | ,, | 18, | ,, | Tubes for igniting gas or petroleum. |
| Pinkney, . . . | 3,203 | ,, | 18, | ,, | Starting large gas engines. |
| Czermak, . . . | 3,292 | ,, | 19, | ,, | Single acting, cooled by air. |
| Humpudge and Snoxall, | 3,417 | ,, | 22, | ,, | Lubricating and starting gas engine. |
| Robert, . . . | 3,574 | ,, | 23, | ,, | Cylinder divided in three compartments. |
| Stuart and Binney, . | 3,909 | ,, | 29, | ,, | Regulating temperature of vaporiser of hydrocarbon. |
| Bickerton, . . . | 4,078 | March | 2, | ,, | Governor. |
| Hamilton, . . | [illegible] | | 3. | ,, | Valves and governing. |

| | | | | | Speciality. |
|---|---|---|---|---|---|
| Lanchester, | 4,210 | March | 3, | 1892. | Governing and igniting. |
| ,, | 4,374 | ,, | 5, | ,, | Operating valves and governing. |
| Richardson and Norris, | 4,375 | ,, | 5, | ,, | Oil supplying for petroleum and liquid fuel engines. |
| Clerk, | 5,445 | ,, | 19, | ,, | Governor and valve gear. |
| Bilbault, | 5,740 | ,, | 23, | ,, | Gas and petroleum, general design. |
| Michels, | 5,819 | ,, | 24, | ,, | Feeding devices for petroleum motors. |
| Owen, | 6,240 | ,, | 31, | ,, | Gas and hydrocarbon, general design. |
| Chatterton, | 6,284 | April | 1, | ,, | Method employing steam and gas for motors. |
| Morani, | 6,655 | ,, | 6, | ,, | Mechanism for distribution and mixing air and gas. |
| Adams, | 6,828 | ,, | 9, | ,, | Rotatory for steam, air, or gas. |
| Shillito, | 6,872 | ,, | 9, | ,, | Petroleum motor, valves and vaporiser. |
| Courtney, | 7,047 | ,, | 12, | ,, | Petroleum motor, supply of air and valves. |
| Diesel, | 7,241 | ,, | 14, | ,, | Producing motive work by heated air, combustion of gases, or mixture of same. |
| Sennett and others, | 7,943 | ,, | 27, | ,, | Utilisation of steam and gases for obtaining power. |
| Hornsby and others, | 8,128 | ,, | 29, | ,, | Piston, cylinder, heating air, and jacketing valve box. |
| Pollock, | 8,401 | May | 4, | ,, | Governor and trip mechanism. |
| Beugger, | 8,538 | ,, | 5, | ,, | Cooling, gas or hydrocarbon engine. |
| Guillery, | 9,121 | ,, | 13, | ,, | Rotatory. |
| Robinson, | 9,161 | ,, | 14, | ,, | Governor and mixing valve. |
| Beugger, | 9,439 | ,, | 18, | ,, | Portable, gas or petroleum motor. |
| Richert, | 10,019 | ,, | 26, | ,, | Heating air to increase energy of same in air, &c., engine. |
| Holt, | 10,437 | June | 1, | ,, | Igniting for gas or oil motors. |
| Hersey, | 10,639 | ,, | 4, | ,, | Producing gas for motive power from decomposition of ammonium, nitrate, and a hydrocarbon. |
| O'Kelly, | 11,593 | ,, | 21, | ,, | Tram car gas motor. |
| Susini, | 14,711 | Aug. | 15, | ,, | Motor by ether or other volatile liquid. |
| ,, | 14,712 | ,, | 15, | ,, | Motor by ether in combination with steam. |
| ,, | 14,713 | ,, | 15, | ,, | Motor by ether vapour. |
| Brigg, | 16,365 | Sept. | 13, | ,, | Lubricator for gas, &c., engine. |
| Redfern, | 16,413 | ,, | 13, | ,, | Hot air motor, general design. |

| | | | | Speciality. |
|---|---|---|---|---|
| Whittaker, | 16,986 | Sept. | 23, 1892. | Ignition tubes. |
| Fairfax, | 17,391 | ,, | 29, ,, | Petroleum motor, no valves (very simple). |
| Held, | 17,632 | Oct. | 4, ,, | Fire engine propelled by portable petroleum motor. |
| Southall, | 18,109 | ,, | 11, ,, | Gas or oil engine (simple). |
| Strok, | 18,808 | ,, | 20, ,, | Reservoir, for petroleum motor. |
| Mein, | 19,054 | ,, | 24, ,, | Pneumatic motor. |
| Enger, | 21,475 | Nov. | 24, ,, | Gas or other motor, general design. |
| Altman, | 21,534 | ,, | 25, ,, | Spray apparatus for hydro-carburetted air engine. |
| Winckler, | 21,857 | ,, | 30, ,, | Feeding oil engines. |
| ,, | 21,858 | ,, | 30, ,, | Reversing gear for oil engines. |
| Durr, | 21,952 | Dec. | 1, ,, | Hydrocarbon motor, general design. |
| Best, | 24,065 | ,, | 30, ,, | Gas motor, vehicles. |

## APPENDIX.—SECTION D.

### SUMMARY OF EXPERIMENTS ON A TWIN-CYLINDER OTTO GAS ENGINE.

By Dr. A. Slaby.

**Object.**—These valuable experiments were made by Dr. A. Slaby, Professor at the Technische Hoch-Schule, Berlin, to investigate the heat cycle in a gas engine. The object with which they were undertaken was, in Dr. Slaby's words, to "determine by measurements the division of heat in a gas engine, in order to deduce therefrom the conditions for the best utilisation of the combustible." They have been published from 1890 to 1892 in six pamphlets, comprising 196 pages, illustrated by many plates and diagrams, and form the most exhaustive treatise on this particular subject with which the author is acquainted. An abstract of their contents is here given, and will, it is hoped, serve as an introduction to that careful study of the original, which Dr. Slaby's laborious researches merit.

The engine experimented on was a twin-cylinder horizontal 8 H.P. German Otto engine, employed for driving the electrical laboratory in the Berlin Technical High School. The gas used was always lighting gas, made from Upper Silesian coal, from the gas-works at Charlottenburg, near Berlin. The diameter of the cylinder was 172·5 mm. = 6·8 inches, and stroke 340 mm. = 13·3 inches. In all, 306 experiments were made, from 1886 to 1890, divided into two sets, but Dr. Slaby is still continuing his work on the same engine. For further details of the motor see p. 391.

**Heating Value of the Gas.**—**Pamphlet I.**—The author begins by expressing his desire to elucidate the various questions still undecided in the theory and practice of the gas engine. With this object it is necessary, he considers, first to determine the composition and heating value of the gas used. The chemical constituents of any gas depend upon the raw material (coal), the process of generation and purification, and time which has elapsed since the beginning of distillation. But the difficulty of arriving at exact knowledge of the heating value and composition of any given g

so great as to be almost insuperable. The subject has never been thoroughly investigated. All that can be done, to ensure uniformity in the constituents of lighting gas during a test, is to carry out the experiments always at the same hour of the day, with gas from the same main.

Not only is the composition of gas given differently by different authorities, but the proportions of heavy hydrocarbons are variously estimated. Some writers class them all as $C_4H_8$, some as $C_2H_4$, some as half one, half the other, producing a difference in the heating value of the gas of 8 per cent. This method was not sufficiently accurate for the author's purpose. After many trials he found that the heat value of each hydrocarbon could be expressed as

$$H = 1{,}000 + 10{,}500 \times \text{ the density of the hydrocarbon}$$

(H representing the heating value in calories per cubic metre), and that this formula was also applicable to any given mixture of the same. It was necessary, therefore, to determine the density of each gas to within $\frac{3}{4}$ per cent., instead of taking the residuum in the gaseous mixture, after analysing the different constituents H, $CH_4$, CO, &c., as nitrogen, and reckoning its weight as such.

To calculate the density of the hydrocarbons, a Schilling apparatus was used, of which a drawing and detailed description are given in the original. By this instrument it was found that the densities of any two gases were inversely proportioned to the squares of their speed of discharge, at the same pressure, through a narrow orifice. The experiment being carried out first with air, then with gas, the density of the latter was thus determined. Great care was taken to ensure an even temperature. Satisfactory results were obtained by these means, but it was necessary to check them by experimenting upon perfectly dry lighting gas; the Schilling apparatus being immersed in water, the gas in it was always slightly damp. The difference between moist and dry gas was considerable. *Saturated air weighed 0·75 per cent. lighter than dry air, but saturated gas weighed 0·94 per cent. heavier than dry gas.* The gas was next directly weighed. Two glass vessels were filled respectively with dry gas and dry air, and after being both brought to the same temperature and pressure, they were weighed. Immediately after, the glass vessels were weighed alone, and the proportional weights of the gas and air thus determined. The correction for the Schilling apparatus was found to be only 0·07 per cent., but this accuracy was obtained after years of practice, comprising about 1,000 determinations. Finally the Lux gas weigher was used, and gave excellent results, about 3·8 per cent. higher than the Schilling, owing to the dryness of the air and gas, and faults in calibrating.

To determine the heat value of lighting gas, the percentage in volume of the heavy hydrocarbons was ascertained by analysis. The specific weight of the gas being known, and the residuum taken as pure nitrogen, the specific weight of the heavy hydrocarbons was deduced from the weight of the gas with and without them. This method has the disadvantage of assuming that the residuum consists entirely of pure nitrogen, whereas it is known to contain ammonia and other substances. A more satisfactory process was as follows:—The gas was first carefully weighed, then passed through tubes and vessels containing glass shavings, sulphuric acid, potash, water, &c., to separate the hydrocarbons and carbonic acid. The purified gas was then again weighed, and the density of the heavy hydrocarbons found by deduction to be a mean of 1·72. This agreed well with the ordinary analysis of Berlin gas. It may therefore be assumed that in any given gas the mixture of heavy hydrocarbons is essentially a constant, the greatest difference in the heat value being 8 per cent. During one day of a trial, the difference was seldom more than 1 per cent. It is necessary, however, in making an experiment, to determine the heat value of the mixture of

heavy hydrocarbons, which vary from 13,000 to 27,000 calories per cubic metre. Throughout the experiments it was taken at 19,000 calories per cubic metre.

**Products of Combustion.**—In the Second Pamphlet the composition of the products of combustion is considered, and the constants determined. The specific weight of 1 cubic metre is 0·417, with a heating value of 4,883 calories. For complete combustion the weight of oxygen required for 1 cubic metre of lighting gas is 1·515 kilo., and of air 6·425 kilos. or 4·965 cubic metres. The combustion produces 6·965 kilos. or 5·684 cubic metres of products, or a contraction of 4·8 per cent. Analyses of the products of combustion with different dilutions of air were carried out on seven different days, and the mean taken. In none of them could any trace of unburnt hydrocarbons or carbonic oxide be discovered. These analyses do not give the percentage of steam, which is certainly superheated, and is reckoned, for the above proportions, at 1·209 cubic metre. The different constants for proportions of 5, 6, 7, and 8 volumes of air to one of gas are shown in a table and plotted out, namely—Percentage of contraction during combustion; weight and specific weight of 1 cubic metre of the mixture before combustion, and of 1 cubic metre of products; and constants of the products.

The next question to determine was the specific heat of the products of combustion. The author distinguishes between true and mean specific heat; the former increases twice as much for a given increase of temperature as the latter. The increase in true specific heat per degree rise in temperature, for the gas composing the products of combustion in a gas engine, is given from Mallard and Le Chatelier, and the values calculated at constant pressure, and at temperatures of 0°, 100°, 500°, 1,000°, 2,000° C. From these the specific heats, at constant pressure, of the products of combustion under the same conditions are reckoned, and plotted out. The horizontal lines show the rise in temperature of the gases from 0° to 2,000°, the verticals the increase in their specific heat at constant pressure, for a given dilution of gas and air.

**Engine and Instruments.**—The experiments to verify these calculations were carried out on the engine already described (drawings of which are given). The quantities of gas, air, and of cooling water were carefully measured. During the experiment only one cylinder was used, the other being employed to determine the piston friction. The quantity of gas was measured by a glycerine gas meter, marked to show half litres, the consumption for the ignition flame being given by a separate meter. Both meters were carefully tested before the experiments, and thermometers inserted in them, from which the temperatures could be read off. From the meters the gas passed to the engine through rubber bags, a pressure gauge being fixed in the admission passage. In all the experiments the air was measured in a gas meter, provided with a scale, thermometers, and pressure gauge. The error in this meter was found to be under ½ per cent. The air was forced into the air meter by means of a small fan, driven by a little water motor. The pressure was determined by passing it, before it entered the meter, through a small air holder, maintained by weights at a constant height. The cooling jacket water passed to the engine through pipes in which small copper tubes were inserted, one at the entrance, the other at the exit; these tubes contained delicately graduated thermometers. The quantity of water was previously measured in gauged tanks, and afterwards passed into another tank.

The governor was not acting during the experiments. The opening admitting the gas could be adjusted by means of a screw, but in the trial the mixture was kept uniform, with the same proportion of gas. Speed counters were arranged on the crank shaft and valves.

**Temperature of Gases at Exhaust.**—The next [illegible]tion was to determine the temperature of the gases of combu[illegible] by

taking the temperature with pyrometers fixed in the exhaust passage, but found an error of 50° in the best instruments. He next operated with ordinary glass, quicksilver, and nitrogen thermometers, marking up to 460° C. By cooling the cylinder very considerably, and greatly reducing the speed, it was possible to reduce the temperature of the exhaust gases to the desired limit. No practical results were, however, obtained until a ball calorimeter was used. In the ordinary exhaust pipe a cock was fixed which, when open, allowed the gases to pass in the usual way into the atmosphere. When closed, the gases of combustion were forced through another channel, joining the main exhaust pipe at a point below the cock. In this pipe was a hollow cock, the socket of which contained an iron ball. By turning the cock 90° either way the ball could be introduced into the socket, or allowed to fall out below. To make an experiment, the gases were first shut off from their usual course, and the side cock opened, causing them to flow through an auxiliary pipe. The ball being previously placed in the socket, and kept in position by wire-netting, it was exposed for half an hour to the current of the hot exhaust gases. A calorimeter containing water was then placed beneath it, the cock turned, and the ball dropped into the calorimeter, when its temperature was determined in the usual way by the rise in temperature of the water. The author thus succeeded in obtaining accurately the temperatures of the exhaust gases which, plotted on a curve, were compared with those arrived at with an ordinary thermometer.

The indicators employed were of various kinds. No brake was used on the engine during the experiments, because the author, who worked for the most part entirely without help, was not able to carry out brake at the same time as calorimetric experiments. The brake efficiency was at other times carefully noted.

**Volume of Clearance Space.**—The compression or clearance space of the engine was 60 per cent. of the total suction volume of the piston. This was determined—1, By direct measurement of the internal dimensions of the cylinder; 2, by filling the cylinder with water, and thus measuring both the compression space and volume engendered by piston.

**Piston Friction.**—The piston friction was next calculated, the heat thereby generated affecting materially the heat balance of the motor. This was done by shutting off one of the two cylinders, and running it without gas; the rise in temperature of the jacket water gave the heat due to the piston friction. Seven experiments were made on two different days, and 50 litres of circulating water used. The trial varied from half an hour to an hour and a half, and the rise in the temperature of the water, corrected for the heat of the room (which was always about 3° higher than that of the water at discharge), varied from 5° to 8°. The number of calories carried off per cycle varied from 0·09 to 0·13. The mean temperature of the walls was about 3° below that of the water at discharge.* The results, when plotted out, showed that the friction of the piston decreased with the rise in temperature of the walls for about the same number of revolutions; in other words, the higher the temperature of the walls, the less heat was carried off by the jacket water, or the less friction was generated. This was clearly revealed by the experiment of the 21st April, 1888, and the piston friction was found to depend not on the speed, but on the mean temperature of the walls. Thus with a mean wall temperature of 9°·4, the heat generated by the piston during two revolutions, or one cycle, was 0·183 calorie, with a wall temperature of 15°·6 it was 0·17 calorie. The speeds varied from 97 to 182 revolutions per minute. These results are worked out and summed up in a table, showing the generation of heat by piston friction, with a wall temperature of 10° to 55°. Taking into account the indicated work, the author arrived at the conclusion that, *the lower the*

* The temperature of the cast-iron cylinder wall was always taken as a mean between the temperature of inlet and outlet of jacket water.

*wall temperature the greater the friction.* With a temperature of 10°, nearly one-third the indicated work was expended in piston friction; it sank to 6·5 per cent., with a wall temperature of 40°, corresponding to a temperature of the water at discharge of 70°. If it were possible to reduce the wall temperature to 3°, the engine would not be able to overcome the frictional resistance.

**General Cycle.—Pamphlet III.**—The amount of heat turned into indicated work during a complete cycle in a gas engine, is influenced by the following factors:—1, Heat value of the gas; 2, piston speed; 3, temperature of the walls; 4, proportion in which the gas is diluted with air, or with neutral gases; 5, amount of compression before ignition. To study a gas engine properly, each of these five should be separately varied, the others being maintained constant. The heat value of the gas having been already considered, the next question is the influence of the piston speed. The author found that his experiments did not confirm the general opinion that the efficiency increased with the speed. The gas consumption per I.H.P. per hour, when the engine was running at 87 and at 180 revolutions per minute, was practically the same, the temperature of the out jacket water varied only 2° or 3°. The I.H.P. was more than one-third higher at the above high speed, but the negative work was greatly increased. "As these results were questioned," says the author, "I repeated my experiments in sets of two together on the same day, and proved that, if a motor is allowed to run continuously for some time, and the speed be increased, certain phenomena intimately connected with it make their appearance, which not only counterbalance the favourable effect of the augmented speed, but act prejudicially in the opposite direction. These influences are principally manifested by the rise in temperature of the products of combustion, and the increase of the negative work, corresponding to the periods of exhaust and admission in the gas engine. The increase in negative work was revealed by the indicator which, with a weak spring, showed that the mean pressure corresponding to the negative work rose from 0·070 kilo. per square centimetre when the engine was running at 92 revolutions, to 0·242 kilo. per square centimetre at 191 revolutions. The temperature at which the products were discharged rose at the same time more than 150°."

Two series of experiments were undertaken to determine the influence of the speed, and yielded results at variance with those obtained by Professor Witz. The temperatures of the jacket water and exhaust gases were measured as described.

The cycle of the gas engine was divided into—1, Admission; 2, Compression; 3, Ignition; 4, Expansion; 5, Discharge, and each of these periods was studied experimentally.

Considering first the admission period, the author found that though the proportion of air to gas varied a little, the mean temperature of the jacket water, or that of the walls, rose slightly, though not in every case, and the temperature of the exhaust gases always, in almost exact proportion to the increase in the speed. With 90 revolutions the exhaust temperature was 400° C., and with 170 revolutions, 529° C. The total volume of the charge drawn in per stroke decreased with increase of speed; with double the revolutions it fell more than 20 per cent. This proportion varied in the different experiments, the difference being less, the higher the speed. It was clearly a result of the available admission volume, which was dependent on the pressures at beginning and end of the cycle, and upon the mean temperatures at these two periods. To determine the pressure during admission, it was necessary to know how far the line of admission varied in pressure from that of the atmosphere. This initial pressure was found to increase in almost exact ratio to the increase of speed, from whence the author concluded that it *depended entirely upon the number of revolutions.*

Other experiments on the back pressure of the exhaust gases showed that, at the moment the exhaust valve closed, the pressure line rose

slightly, in fairly exact proportion to the number of revolutions. It was always higher with increase of speed, varying from 8 mm. with 98 revolutions, to 14 mm. with 184 revolutions (scale—29 mm. = 1 kilo. per sq. cm.) Plotting out the values obtained, the author found that, however the conditions of discharge were varied, the pressures always rose with the increase of speed, but much more gradually after the engine had been running for an hour, and a certain equilibrium in working was obtained. Thus the exhaust as well as the initial pressure depended entirely on the speed.

The temperatures at admission and discharge of the gases remained to be considered. The first the author had no means of determining. The temperature of the products of combustion left in the cylinder is about the same as that determined with the calorimeter and ball, but at the moment the exhaust valve opens, the author verified a sudden momentary rise of 2° or 3°. Nevertheless he assumed that the mean temperature of the products in the cylinder, and of the exhaust gases, was the same. The temperature of the exhaust gases was higher in the one set of experiments than in the other, about 3 per cent. absolute temperature at 150 revolutions, although the speed and the volume of the charge were the same, and this was explained by the difference in pressure, which was 14 per cent. By itself this difference should have produced a higher exhaust temperature; but the mean temperature of the walls was on the other hand 5° lower, thus showing their influence on the temperature of the exhaust. The temperature of the charge in the cylinder at the end of admission was obtained by calculation. Plotted out on curves, the figures showed that this temperature also increased with the speed, but not much. With double the number of revolutions, the increase was only from 106° C. to 128° C. The two experiments showed the same variation of temperature as before verified, about 7° at equal speeds (150 revolutions). Hence the mean temperature of the products left in the cylinder had but a slight influence upon the mean temperature of the freshly admitted charge. The author was able to determine with certainty that the temperature of the charge at admission was about 100° higher than that of the cooling water at discharge.

He sums up these researches by stating that the differences in the volume of the charge can be explained only by these differences of pressures and temperatures, which he formulates thus—

$$\frac{\text{pressure at admission of charge}}{\text{abs. temperature at admission of charge}} = 31 - 0{\cdot}049 \times \text{number of revs.},$$

$$\frac{\text{pressure at exhaust}}{\text{abs. temperature at exhaust}} = 22{\cdot}64 - 0{\cdot}0238 \times \text{number of revolutions.}$$

These were the values for the first set of experiments. They differed in the second experiments chiefly in respect to the exhaust temperature and pressure, which, unlike the admission pressure and temperature, *depended on the mean wall temperature as well as the speed.*

**Walls during Admission—Speed Effect.**—The author next endeavoured to determine the action of the walls during admission, their temperature being then lower than that of the gases in the cylinder. The difference between the heat given off by the products in the cylinder, and that absorbed by the fresh charge passes into the cooling water, and it is necessary to know the weights of the products, of the gas, and of the air composing the charge. The weight of the products he found to diminish in *exact* ratio to the increase of speed, being with 90 revolutions 3·21 grammes, with 184 revolutions 2·88 grammes. The specific heat of the products increases. On the other hand, the heat carried off to the cooling water during admission increases greatly with the speed. In the first set of experiments it rose from 0·08 cal. to 0·16 cal., the speed being doubled, and in the second from

0·02 cal. to 0·10 cal. for the same increase of speed, the temperature of the walls in the latter case being about 5° higher. "It follows," says Dr. Slaby, "that for the heat given off to the walls the rise in temperature of the products, increasing with the speed, has a far greater effect than the diminished time of contact with the walls."

Hence he deduces that the pressures and temperatures at admission and exhaust are variable, and depend on the speed, and the mean temperature of the walls. The admission pressure and temperature depend on the speed, and are but slightly affected by the temperature of the products with which the fresh charge mingles, and that of the cooling water. The exhaust temperature and pressure are greatly affected by the walls. If no water is allowed to collect in the exhaust pipe, the pressure of exhaust becomes a function of the speed, and the proportion of pressure to temperature of exhaust, the wall temperature and dilution of the charge being maintained constant, can be approximately calculated from the speed. Thus formulæ are obtained for calculating the volume of the charge admitted per stroke, the total weight (including that of the products) and quantity of heat given to the cooling jacket. The author considers that the greater the number of revolutions the smaller the charge, and he says further:—"If the quantity of gas admitted is smaller at high than at low speeds, it will be evident that the difference between the heat given off by the products during admission, and the heat taken up by the freshly admitted charge must be considerably increased by increase of speed."

**Indicators.**—Pamphlet IV.—The least known part of the gas engine cycle is that comprising the ignition and expansion of the charge. There is only one way of determining the connection between the spread of the flame and the cooling influence of the walls, namely, an analysis of the indicator diagram. The author, therefore, devotes the whole of this pamphlet to an exhaustive study of indicators (Crosby and others) and a determination of their limits of error. The indicators chiefly used during the experiments were a Crosby and a Storchschnabel.

**Compression.**—Pamphlet V. deals with compression in the gas engine. During this period the amount of heat set in motion and its direction should be determined. The problem is simple, if the compression curve be replaced by a "polytropic" * curve.

$$p\,v^m = \text{const.}$$

The initial pressure having been shown to depend entirely on the speed, the compression pressures must be taken from the diagrams. The mean pressures for two sets of experiments are given in tables, and when plotted out, the abscissæ representing the number of revolutions, and the ordinates the pressures of compression in millimetres above atmosphere, these compression pressures are shown to follow a strict law, and to decrease in proportion to the increase of the speed. This law the author reduces to a formula. From the two sets of experiments he lays down the proposition that *the compression pressure depends entirely upon the speed of the engine, and can be reckoned by a given formula.* Desiring next to know if the compression curve agreed with the polytropic during its whole course, he calculates the pressures, at half way through the stroke, from all the diagrams of the second set of experiments. They were also found to diminish with increase of speed, though not to the same extent as the initial pressures, and thus the compression curve agreed with the polytropic throughout its course, and could be accurately calculated, the exponent being 1·29. To prove its variation from the adiabatic, the author reckoned the specific heat for both curves at

* "Polytropic" is the name given by Zeuner to any curve which can be represented by the formula $p\,v^m$ = constant. The isothermal and adiabatic curves come under this law, with different exponents, $m$; the polytropic may be called the generic curve, of which the isothermal and adiabatic are varying forms. For a full explanation of the law, see Zeuner. *Thermodynamik*, and Schöttler.

constant pressure and volume of the mixture of gas, air, and products. It was considerably higher for the adiabatic than for the polytropic curve, with which he had proved the compression curve to agree, and hence he concludes that *during compression there is a loss of heat to the walls.* Other conditions being equal, this compression pressure is a function of the speed. Thus at 100 revolutions, the initial pressure being atmospheric, the pressure of compression is 3·50 kilos. per square centimetre; at 200 revolutions (double speed) it is 3·06 kilos.

The mean temperature during compression increases with the speed. With a mean temperature of 200° C. the specific heat of the products of combustion is 11·5 per cent. higher than at 0°. The mean rise is 130°, the proportion between the initial and compression temperatures remaining constant at 1·32. The work of compression, especially the increase in the internal work, also depends upon the speed. The change of condition is accompanied by a carrying off of the heat, but this abstraction of heat is small, and slightly diminishes with increase of speed.

**Ignition Period.**—The next question considered is the ignition period. This can only be studied by the help of the indicator diagrams taken by the author in each experiment. The differences in the diagrams obtained under precisely similar conditions the author attributes to the varying composition of the gas mixture which, even if the valve action is perfectly regular, is subject to uncontrollable fluctuations, due to slight differences in the speed of ignition. It is well known from Mallard and Le Chatelier's experiments that the speed of ignition increases up to a maximum with increasing richness in the gas mixture, but if the proportion of gas be still greater, it falls again. The indicator diagrams showing the effect of a richer or poorer mixture give curves sinking regularly one below the other with the decrease in the proportion of gas in the mixture, but do not explain the variation in the rounding shape of the top of the diagram. The author does not attribute this to the ignition flame, but considers that it is probably caused by differences in the local arrangement of the charge, and not by fluctuations in the strength of the mixture, which can hardly occur when the engine is running regularly. The small, perfectly vertical part of the indicator diagrams obtained by him is due to the force of the explosion in the ignition port; the rest of the line, deviating more or less from the perpendicular, represents the ignition of the remainder of the charge. At the top of all diagrams (taken with double springs) he found a distinct "nick," marking the point where expansion and fall of pressure began. To this, the point of highest temperature in the cycle, he devoted careful study.

Considering first the temperature and pressure of compression, and of this maximum point in the diagram, he reckons the mean specific heat of the charge at constant volume from that at these two points. The amount of heat shown by the diagrams in the area enclosed between the point of highest compression and of maximum temperature (ignition), the atmospheric line and the corresponding ordinate of pressure, is always less than that set free by the combustion of the gases. This difference in heat must be accounted for in one of three ways. Either it is developed during this period, in which case it must be entirely absorbed by the walls; or incomplete combustion, "nachbrennen" takes place; or both processes are combined. Analyses of the products prove that, at some period of the stroke, there is perfect combustion of the whole gaseous mixture. If the heat passes into the walls, the amount thus transferred must be in proportion to the surfaces in contact, time of exposure, and difference of temperature. If "nachbrennen" is produced, it must depend on the proportional composition of the charge, and on the speed, and be increased by poorer mixtures and greater speeds. The figures obtained by the author show, especially with reference to the speed, that this is *not* so. Taking the difference between the total heat of the charge at this point of the stroke, and the heat of combustion shown in the diagrams, and plotting them out, the

author finds the percentage of this difference to be higher with low than with greater speeds, being 8·5 per cent. with 179 revolutions, and 13·2 per cent. with 100·6 revolutions. At 150 revolutions about 10 per cent. of the total heat disappeared. As neither the surfaces nor the maximum temperatures vary much, the differences producing this loss of heat must lie in the time of wall contact. If all this heat passes into the walls, it will be proportioned to the time the indicator pencil takes to travel from the compression to the ignition point, or what the author calls the "time of ignition." The phenomenon cannot be caused by irregularities in the action of the engine, because these, when tested for time with the usual tuning-fork apparatus, were found to be less than ½ per cent.; the speed was therefore constant.

The author proceeds to find the angle through which the crank passes during this period, and expresses in a formula the proportion between the distance passed through, and the angle of crank revolution. By these means he was able to determine the time occupied in traversing the distance, in proportion to the speed, which, when plotted out, showed that the shorter the time the less heat disappeared. The increase in the heat lost was proportioned to the duration of combustion. Hence the author assumes that, *at the point of highest temperature combustion is ended, and the heat not shown in the diagrams has wholly passed into the walls.*

**Speed of Ignition.**—Having thus arrived at the time of ignition, the author was able to determine approximately the speed of ignition. By calculation and measuring the diagram, he reckoned the total length of the ignition channel in proportion to the length of stroke, and was thus able to express the ignition speed in a formula. This speed of ignition was nearly doubled with twice the number of revolutions, being for 100 revolutions 2·6 metres per second, and for 180 revolutions 4·5 metres. These figures agree with Mallard and Le Chatelier, who found that the speed of ignition increased greatly when the gas was in a state of violent motion, and attributed the phenomenon not only to conduction, but to differences of speed in the component parts of the gas. As the charge in a gas engine must be in violent motion during ignition, combustion is really complete at the point of maximum temperature, between ignition and expansion. Thus there is a sudden explosion and rise in pressure at first, then a powerful flame darts into the cylinder, and with a smaller speed of propagation ignites the whole charge. This speed of propagation is affected by—Composition of the mixture; speed of the engine (shown in the more rapid motion produced in the cylinder); the particular local stratification of the gaseous mass, whether homogeneous or otherwise. Combustion is completely ended in from 0·03 to 0·06 second, corresponding to the maximum mean temperature, after which expansion, without addition of heat, takes place. No dissociation is possible, since the maximum temperature is never above 1,600° C. During combustion the flame certainly comes in contact with the walls, and transfers to them some of its heat. But this is only from 8 to 13 per cent. of the total heat, and therefore, considering the difference between the heat conductivity of the metal and that of the products of combustion, we may conclude that this contact does not last long. The process of combustion chiefly takes place in the kernel of the charge, surrounded by neutral gases. The author therefore is of Otto's opinion, and considers that the composition of the centre of the charge not being homogeneous, a more favourable economic effect is produced.

**Expansion Period.**—Pamphlet VI. treats of the period of expansion. The author calculates the heat lost to the walls during this period from the difference between the area of work in the diagram, and the total heat of the gaseous mass. The expansion curve he divides into sections, and traces polytropic curves from one ordinate of pressure to the next. The exponent, already given, is governed by the speed. The values thus obtained are plotted out, and when compared with true adiabatic curves, the author

found that during expansion *there is a continuous carrying off of a large amount of heat to the walls, the temperature falling at first, and then rising.* This is explained by the combined influence of the decreasing temperature and increasing wall surface exposed. At the beginning of expansion, the quantity of heat carried off is determined by the temperature, at the end of expansion, by the cooling wall surface. It is only at a speed of 400 revolutions per minute that the expansion curve approximates to the adiabatic.

Considering next the fact, shown already to be probable, that during expansion no increase of heat is produced by internal heating, the heat parted with externally must be at the expense of the internal energy of the gas. This can be calculated from the temperatures and the corresponding specific heats at constant volume. The difference between this internal energy and the external work done shows the amount of heat imparted to the walls. These three quantities can be expressed either as heat or as work. As work they may be measured on the indicator diagram as functions of the lengths of stroke, and represent the divisions of heat. The two quantities of internal and external heat are reckoned for any given portion of the stroke, converted into units of work, and divided by the volume passed through by the piston. Plotted out, they show that the abstraction of heat by the walls follows a regular course. At first the walls are relatively very cool, and the temperature of explosion very high. As the wall temperature rises, less heat is abstracted, and at the end of combustion a minimum is reached. The heat curve now rises, because the cooling surfaces are increased by the out stroke, but about the middle of the stroke another fall is produced by the increased piston speed. It again rises at the end of the stroke, as the speed is reduced. These curves show only the amount of heat actually abstracted, and do not enable us to verify the progress of combustion, and whether part of the heat carried off is developed by "nachbrennen." They reveal, however, that the heat parted with to the jacket during expansion, is inversely as the speed. The higher the speed, the less heat is carried off.

**Exhaust Period.**—This may be divided into two parts. During the first, occupying the last tenth of the forward stroke, a portion of the gases escape, carrying off part of the total energy of the charge, in the shape of "*force vive*," or "energy of exhaust" (as Zeuner calls it). The remainder of the gases are discharged at lower speed during the return stroke. The author endeavours to determine the heat value of this "energy of exhaust" from the heat balance of the engine. The heat received is the heat set free by the combustion of the lighting gas. The heat going out is divided into—1, Indicated work, both positive and negative, measured from the area of the diagrams, and reduced to calories. 2, Heat passing into the walls and carried off into the cooling water, less the heat absorbed in piston friction. The latter heat value is calculated, as before stated, from the rise in temperature of the jacket water and the quantity used, which was always 200 litres; the time of passing this quantity through the jacket varied from fourteen to twenty minutes. 3, The appreciable heat carried off in the products of combustion. The weight of the products is known, being the same as the weight of gas and air admitted per stroke. Their mean temperature is calculated from the weight of the gas and air, plus their specific heat at constant pressure, and the difference between the temperatures at admission and exhaust. The values obtained are shown in a table. 4, Heat value of the work of resistance during exhaust. This is reckoned from the difference in volume, namely, the increase during the time from the opening of the exhaust valve to the end of the stroke (about one-tenth of stroke), and is distinct from the heat value of the return or exhaust stroke. 5, The "energy of exhaust," or the momentum of the products at the beginning of exhaust, shown by the difference between the pressure at the opening of the

exhaust valve and the constant back pressure during the return exhaust stroke. This difference is plotted on a curve.

The variations shown are referred by the author to the accumulated action of the walls. Time is necessary, that the metal may reach a state of thermal equilibrium. At the beginning of an experiment the walls are still affected by the preceding trial, and contain more or less heat, according to the previous speed of the engine. In this way the author determines the heat accumulated in the walls, that taken up by them, but not carried off in the cooling jacket, and that withdrawn from the walls, but not from the cycle. The values obtained for this "energy of exhaust" give the mean speed of the gases during the last tenth of the forward stroke, reckoned from their weight, as compared with the total weight of the products during exhaust. The speed depends on the mean speed of the engine.

Lastly, the total heat discharged from the beginning of exhaust to the admission of the fresh charge is reckoned, and the difference between it and the heat of the products remaining in the cylinder. It represents an energy transformed into—I. Energy of discharge; II. Back pressure negative work; III. Work of exhaust; and IV. Energy carried off in the water. The author concludes that, in the escaping gases and the products remaining in the cylinder, there is a certain amount of energy or work represented by their temperature. The difference between this temperature and that at the closing of the exhaust valve represents a loss of energy carried off during exhaust into the atmosphere, or to the walls. There is a perceptible increase in this heat parted with to the walls, with increase of speed in the engine.

## APPENDIX—SECTION E.—TABLE OF TRIALS—

| Gas Engine. | Experiment made by | Place and Date. | Duration of Test. | Dimensions of Engine. | | Number of Revs. per min. |
|---|---|---|---|---|---|---|
| | | | | Diam. of Cylinder. | Stroke. | |
| Lenoir (old type), | Tresca | Paris, Jan., 1861 | $3\frac{1}{2}$ hours | $7\frac{1}{16}$ ins. | 4 ins. | 130 |
| ,, ,, | ,, | ,, March, 1861 | 5 ,, | $9\frac{1}{2}$ ,, | $4\frac{3}{4}$ ,, | 94 |
| ,, ,, | Clerk | London, Dec., 1885 | 2 ,, | $7\frac{1}{8}$ ,, | $11\frac{1}{4}$ ,, | 85 |
| Hugon, | Tresca | Paris, Feb., 1866 | 5 ,, | 13 ,, | $12\frac{3}{4}$ ,, | 53 |
| Brayton, | Thurston | New York, 1873 | ... | ... | ... | ... |
| Simon, | ... | ... ... | ... | $9\frac{1}{4}$ ,, | $15\frac{1}{2}$ ,, | 146 |
| Beck, | Kennedy | London, Feb., 1888 | $2\frac{1}{2}$ ,, | 7·5 ,, | 15 ,, | 206 |
| Otto and Langen, | Tresca | Paris, Sept., 1867 | $\frac{1}{2}$ ,, | $5\frac{9}{10}$ ,, | ... | 81 |
| ,, ,, | Clerk | Oldham, Aug.,1884 | $1\frac{1}{2}$ ,, | 12·5 ,, | 40·5 ,, | 28 explosions. 180 revs. |
| Otto (German type), | Brauer & Slaby | Berlin, Mar., 1878 | $1\frac{1}{2}$ ,, | $5\frac{1}{2}$ ,, | 11 ,, | |
| ,, ,, | Brauer & Slaby | Erfurt, Aug., 1878 | $1\frac{1}{2}$ ,, | $6\frac{7}{10}$ ,, | $13\frac{1}{2}$ ,, | 160 |
| ,, ,, | Slaby | Deutz., Aug., 1881 | $\frac{1}{2}$ ,, | $6\frac{7}{8}$ ,, | $13\frac{1}{2}$ ,, | 157 |
| ,, ,, | Brauer & Schöttler | Altona, Sept., 1881 | 1 ,, | ... | ... | 159 |
| ,, ,, | Meidinger | Karlsruhe. 1882 | 24 mins. | ... | ... | 159 |
| ,, ,, | Allard & Tresca | Paris, 1881 | ... | $6\frac{7}{10}$ ,, | $13\frac{4}{10}$ ,, | 155 |
| ,, ,, | Witz | Roubaix, 1883 | 39 ,, | $6\frac{7}{10}$ ,, | $13\frac{4}{10}$ ,, | $159\frac{1}{2}$ |
| Otto-Crossley, | Garrett | Glasgow | ... | 9 ,, | 16 ,, | 154 |
| ,, ,, | Brooks & Steward | Hoboken,U.S.,1884 | 30 ,, | 8·5 ,, | 14 ,, | 158 |
| ,, ,, | Adams | Crystal Palace,1881 | ... | 13 ,, | 21 ,, | 151·3 |
| ,, ,, | ,, | ,, ,, | ... | 12 ,, | 16 ,, | 158·7 |
| ,, ,, | ,, | ,, ,, | ... | $5\frac{3}{4}$ ,, | 12 ,, | 160 |
| ,, ,, | Society of Arts | London, Sept., 1888 | 6 hours | 9·5 ,, | 18 ,, | 160 |
| ,, ,, | Kidwell & Keller | Pennsylvania | 3 ,, | ... | ... | 161·6 |
| ,, ,, | Capper | London, 1892 | 2 ,, | 8·5 ,, | 18 ,, | 162·5 |
| Clerk, | Garrett | Glasgow, 1885 | ... | 7 ,, | 12 ,, | 146 |
| ,, | ,, | ,, ,, | ... | 9 ,, | 20 ,, | 132 |
| Atkinson (Differential Engine), | Robinson | London | 1 ,, | ... | ... | 148 |
| ,, ,, | Schöttler & Atkinson | Magdeburg, 1886 | $\frac{1}{2}$ ,, | ... | ... | 159 |

## GAS ENGINES USING LIGHTING GAS, 1861-1893.

| Indicated H.P. | Brake H.P. | Cub. ft. of Gas burnt per I.H.P. per hour, including ignition. | Cub. ft. of Gas burnt per B.H.P. per hour, including ignition. | Mechanical Efficiency. | British T.U. per I.H.P. per hour. | Authority. The word "diagram" in this column means that an indicator diagram of the trial is given in the text. |
|---|---|---|---|---|---|---|
| ... | 0·57 | 112 | ... | ... | ... | *Annales du Conservatoire des Arts et Métiers.* |
| ... | 0·90 | 96 | ... | ... | ... | " " |
| 1·17 | ... | 73·5 | ... | ... | ... | Clerk, *On the Explosion of Gaseous Mixtures*, p. 43. |
| 3·55 | 2·07 | 92 | ... | 0·58 | ... | *Annales du Conservatoire des Arts et Métiers.* |
| 8·62 | 3·98 | 32·06 including pump | ... | ... | ... | Clerk, *The Gas Engine*, p. 158. |
| 5·60 | 4·20 | 50 | ... | 0·75 | ... | Richard. |
| 8·05 | 6·31 | 21·68 | 27·67 | 0·78 | 12,682 | Professor Kennedy's Report, Diagram. |
| ... | 0·46 | ... | 48·7 | ... | ... | *Annales du Conservatoire.* |
| 2·9 | 2·0 | 28·6 | 42 | 0·69 | 19,999 | Clerk, *Gas Engine*, Diagram. |
| 3·20 | 2·08 | 40·2 | ... | 0·65 | 22,069 | Witz, *Moteurs à Gaz*, p. 206. |
| 6·03 | 3·98 | 38 | ... | 0·66 | ... | " " |
| 5·04 | 4·4 | 28·3 | 32·4 | 0·87 | 12,094 calories per kil. | Jenkin, *Gas and Caloric Engines*, Diagram. |
| 4 nom. | 3·96 | ... | 32 | ... | ... | Schöttler, *Die Gas Maschine*, p. 87. |
| 4 " | 4·11 | ... | 33 | ... | ... | " " p. 86. |
| 5·26 | 3·94 | ... | 31 | 0·74 | 18,841 | Witz, *Moteurs*, p. 209 (Twin cylinder engine). |
| 3·3 | 3·7 | ... | 39 | 0·85 | ... | " " p. 210. |
| 14·26 | 9·08 | 19·4 | 28·0 | 0·63 | ... | Clerk, *Gas Engines*, p. 181, Diagram. |
| 9·6 | 8·1 | 24·5 | 29·1 | 0·83 | 15,118 | " " p. 175, Diagram. |
| 33·6 | 27·75 | 25·04 | 30·3 | 0·82 | 16,000 | Inaugural Address to Society of Electricians, 1884. |
| 22·56 | 18·31 | 23·6 | 29·1 | 0·81 | 15,080 | |
| 3·42 | 2·87 | 30·9 | 33·4 | 0·84 | 19,745 | |
| 17·12 | 14·74 | 20·76 | 24·10 | 0·86 | 12,120 | Report of Trial, Diagram. |
| 4·94 | ... | 22 | ... | ... | ... | Witz, *Moteurs*, p. 217, Diagram. |
| 13·32 | 11·33 | 20·87 | 25·22 | 0·85 | ... | Page 355 of this work. |
| 9·05 | 7·23 | 24·30 | 30·42 | 0·80 | 19,755 | Clerk, *Gas Engines*, p. 191, Diagram. |
| 27·46 | 23·21 | 20·39 | 24·12 | 0·84 | 16,577 | |
| 2 nom. | 2·6 | ... | 25·77 | ... | ... | Robinson, *Gas and Petroleum Engines*, p. 45. |
| ... | 2·22 | ... | 30·5 | ... | ... | Schöttler, *Die Gas Maschine*, p. 168, Diagram. |

TABLE OF TRIALS—GAS ENGINES

| Gas Engine. | Experiment made by | Place and Date. | Duration of Test. | Dimensions of Engine. | | Number of Revs per min. |
|---|---|---|---|---|---|---|
| | | | | Diam. of Cylinder. | Stroke. | |
| Atkinson (Cycle Engine), | Unwin | London, Apr., 1887 | 1 hour | 7·5ins. | 9·25ins. | 148 |
| " " | Society of Arts | " Sept., 1888 | 6 " | 9·5 " | 12·43 " | 131 |
| " " | Committee on Science and Art | Franklin Inst. | 32 mins. | ... | ... | 128 |
| Griffin, | Society of Arts | London, Sept., 1888 | 6 hours | 9·2 " | 14 " | 198 |
| " | Kennedy | Kilmarnock, 1888 | 4 " | 9 " | 14 " | 224 |
| " | Jamieson | " Nov., 1887 | ... | 9 " | 14 " | 183 |
| Bisschop, | Meidinger | ... ... | ... | ... | ... | 81 |
| Fawcett, | Miller | Liverpool, Feb., 1890 | ... | 8 " | 16 " | 151 |
| Ajax, | Jamieson | Glasgow, Mar., 1889 | ... | 8 " | 15 " | 173·5 |
| Acmé, | Rowden | " Dec., 1890 | ... | ... | ... | ... |
| Forward, | Robert Smith | Birmingham, May, 1888 | 85 mins. | 7·02 " | 15·10 " | 176·8 |
| Simplex, | Witz | Rouen, Nov., 1885 | 2 hours | 7⅞ " | 15¾ " | 161 |
| Lenoir (new type), | Tresca | Paris, May, 1885 | 2 " | 5½ " | 11 " | 176 |
| " " | Hirsch | " May, 1890 | ... | 9 " | 15¾ " | 160 |
| Niel, | Moreau | " Jan., 1891 | 4 " | 7 " | 14 " | 160 |
| Ravel, | Monnier | " Apr., 1889 | 30 mins. | 7 1/16 " | 14⅛ " | 161 |
| Charon, | Witz | Solre-le-Chateau, Apr., 1889 | 22 " | 7 1/16 " | 14⅛ " | 166 |
| Wittig and Hees, | Brauer & Schöttler | Altona, 1881 | 40 " | 7⅞ " | 7 1/16 " | 103 |
| Koerting-Lieckfeldt (old type), | Schöttler | ... ... | ½ hour | 7 1/16 " | 14⅛ " | 119 |
| Koerting (new type), | Fischer | Hanover, Dec., 1890 | ... | ... | ... | 151 |
| " " | E. Müller | Feb., 1889 | ... | ... | ... | 204 |
| Benz, | ... | Carlsruhe, 1886 | 40 mins. | ... | ... | 152·6 |
| Adam, | Richard | Carlsruhe, 1886. | 34 " | ... | ... | 167·8 |
| " | Prof. Aeppli | Winterthur, 1889 | 1 hour | ... | ... | 180·6 |
| " | Schröter | Munich, Jan., 1886 | 43 mins. | ... | ... | 173·8 |
| Lützky, | Schöttler | Harburg, 1891 | ... | ... | ... | 200 |

USING LIGHTING GAS—*Continued.*

| Indicated H.P. | Brake H.P. | Cub. ft. of gas burnt per I.H.P. per hour, including ignition. | Cub. ft. of Gas burnt per B.H.P. per hour, including ignition. | Mechanical Efficiency. | British T.U. per I.H.P. per hour. | Authority. The word "diagram" in this column means that an indicator diagram of the trial is given in the text. |
|---|---|---|---|---|---|---|
| 5·56 | 4·89 | 19·78 | 22·50 | 0·88 | 12,435 | Report of Trial, Diagram. |
| 11·15 | 9·48 | 19·22 | 22·61 | 0·85 | 11,250 | ,, ,, |
| ... | 10·03 | ... | 22·25 | ... | ... | Report. |
| 15·47 | 12·51 | 23·10 | 28·56 | 0·80 | 13,390 | Report of Trial, Diagram. |
| 17·46 | 14·94 | 18·92 | 23·58 | 0·85 | 12,089 | Report. |
| 17·28 | 13·6 | 19·27 | 24·48 | 0·78 | 12,313 | Report of Trial, Diagram. |
| ... | 0·45 | 74 | ... | ... | ... | Schöttler, *Die Gas Maschine*, p. 30. |
| 11·49 | 8·52 | 18·4* | 24·74 | 0·74 | 13,082 | Miller, *On Efficiency*. |
| 10·04 | 8·84 | 18·9 | 21·5 | 0·87 | 15,365 | ,, ,, |
| 6 nom. | 8·28 | ... | 17·3 | ... | 14,064 per B.H.P. | Report of Trial. |
| 5·54 | 4·8 | 20·79 | 23·97 | 0·86 | 13,284 | Report of Trial, Diagram. |
| 9·10 | 8·79 | ... | 20·38 | ... | 13,338 per B.H.P. | Witz, Report. |
| 2 nom. | 1·93 | ... | 23·19 | ... | 14,887 ,, | Report of Trial, Diagram. |
| 16 ,, | 16·13 | ... | 21·2 | ... | 13,610 ,, | Report (Two-cylinder engine). |
| 5·26 | 4·71 | ... | 27·2 | 0·79 | 17,462 ,, | *Comptes Rendus*, Soc. des Ingénieurs Civils, Oct., 1891, Diagram. |
| 9·31 | 7·01 | ... | 37·7 | 0·75 | ... | Witz, *Moteurs*, p. 218. |
| 4 nom. | 4·18 | ... | 18·6 | ... | 13,446 ,, | ,, ,, |
| 4 ,, | 3·75 | ... | 43·5 | ... | ... | Schöttler, *Die Gas Maschine*, p. 146. |
| 3 ,, | 2·18 | ... | 45 | ... | ... | Witz, *Moteurs*, p. 208. |
| 16 ,, | 20·13 | ... | 23·8 | ... | ... | Report of Trial. |
| ... | 5·55 | ... | 30·0 | ... | ... | Report (Twin-cylinder engine). |
| 4 nom. | 5·61 | ... | 25 | ... | ... | Schöttler, *Die Gas Maschine*, p. 159. |
| 4 ,, | 4·47 | ... | 31 | ... | ... | Report of Trial. |
| 2 ,, | 2·46 | ... | 33 | ... | ... | ,, ,, |
| 10 ,, | 11·16 | ... | 31·6 | ... | ... | ,, ,, |
| ... | 6·29 | ... | 24 | ... | ... | *Zeitschrift des Vereines deutscher Ingenieure*, Aug. 22, 1891. |

* Excluding ignition.

## TABLE OF TRIALS OF GAS ENGINES

| Gas Engine. | Experiment made by | Place and Date. | Dimensions of Engine. Diam. of Cyl. | Stroke. | Duration of Test. | No. of Revolutions. |
|---|---|---|---|---|---|---|
| Otto, . . . . . . . | D. K. Clark | 1881 | ... | ... | ... | 156 |
| Otto (German type), | Teichmann and Böcking | Deutz, 1887 | $13\frac{4}{16}$ | in. ... | 6 hrs. | 140·5 |
| " . . . . . . . | Beck | Nuremberg, 1888 | ... | ... | 5 " | ... |
| " . . . . . . . | Monaco, Italy | Canale, Jan., 1890 | ... | ... | 8 " | 140 |
| Crossley-Otto, . . . | Crossley | Dec., 1882 | 13 in. | 18 in. | ... | ... |
| " " . . . | Spicer | Godalming | several | engines | ... | ... |
| " " . . . | Severn Tweed Co. | Dec., 1891 | ... | ... | 56 hrs. | ... |
| " " . . . | Dowson | Mead., Chelsea, Feb., /92 | 17 in. | 24 in. | 8 " | 155·7 |
| Atkinson (Cycle Engine), | Tomlinson | Uxbridge, Oct., 1891 | 14 " | $14\frac{3}{16}$ in. | 6 " | 86 |
| Simplex, . . . . . | Witz | Nov., 1885 | $7\frac{7}{8}$ " | $15\frac{3}{4}$ in. | 2 " | 164 |
| " . . . . . . | " | Sept., 1890 | 22·6 " | 38 in. | $23\frac{1}{2}$ " | 100·8 |

## TABLE OF OIL ENGINE

| Oil Engine. | Spec. grav. of Oil. | Experiment made by | Place and Date. | Dimensions of Engine. Diam. of Cyl. | Stroke. | Duration of Test. | No. of Revolutions. |
|---|---|---|---|---|---|---|---|
| Brayton, . . | 0·85 | Dugald Clerk | Glasgow, Feb., 1878 | 8 in. | 12 in. | ... | 201 |
| Priestman, . . | 0·79 | Unwin | Plymouth, 1889 | $8\frac{1}{2}$ " | 12 " | ... | 204 |
| " . . | ... | " | Hull, 1891 | ... | ... | $3\frac{1}{2}$ hrs. | 207·7 |
| " . . | 0·81 | " | Plymouth, 1890 | $8\frac{1}{2}$ in. | 12 in. | $2\frac{1}{2}$ " | 180 |
| " . . | ... | W.T. Douglass | Plymouth, 1891 | twin. | cyl. en | gine | ... |
| Hornsby-Akroyd, | 0·85 | Robinson | ... | $8\frac{1}{2}$ in. | 14 in. | 3 hrs. | 224 |
| Trusty, . . . | 0·81 | Beaumont | Guildford | $7\frac{3}{4}$ " | 14 " | 2 " | 230 |
| Otto, . . . . | 0·82 | Otto | Dentz | ... | ... | 40 min. | 212 |
| Lenoir, . . . | ... | Tresca | Paris, 1885 | ... | ... | $4\frac{1}{2}$ hrs. | 159 |
| Durand, . . | 0·69 | ... | ... | ... | ... | 2 " | 180 |
| Forest, . . . | ... | Martin | Brest, 1890 | 6·3 in. | 13·4 in. | 7 " | 166·7 |
| Lüde Langensienen. | 0·82 | Schöttler | Magdeburg, 1891 | 7·1 " | 7·9 " | 1 " | 325 |

USING DOWSON GAS, 1881-1892.

| Indicated H.P. | Brake H.P. | Fuel consumed per I.H.P. per hour. Anthracite. | Fuel consumed per B.H.P. per hour. Anthracite. | Mechanical efficiency. | Authority. The word "diagram" in this column means that an indicator diagram of the trial is given in the text. |
|---|---|---|---|---|---|
| 4·41 | 3·26 | 1·45 lbs. | 1·97 lbs. | 0·74 | Dowson, *Cheap Gas for Motive Power*, *Inst. C. E.*, vol. lxxiii. |
| ... | 50·8 | ... | 1·7 ,, | ... | Schöttler, *Die Gas Maschine*, p. 102, Twin-cyl. engine. |
| ... | 30 | ... | 1·97 ,, | ... | Dowson, *Gas Power*. |
| ... | 35·95 | ... | 1·9 ,, | ... | Dowson, *Gas Power*, *Inst. Civil Engineers*, vol. cxi. |
| 27·5 | ... | 1·4 lb. | ... | ... | Dowson, *Cheap Gas for Motive Power*, *Inst. C. E.*, vol. lxxiii. |
| About 400 total | ... | 1 ,, | ... | ... | Dowson, *Gas Power*, *Inst. Civil Engineers*, vol. cxi. |
| 60 nom. | 96·03 | ... | 1·23 ,, | ... | *Journal of Gas Lighting*, Jan. 5, 1892. |
| 118·7 | ... | 0·762 lb. | ... | ... | *The Engineer*, Feb. 12, 1892, Diagram. |
| 21·9 | ... | 1·06 ,, | ... | ... | *The Engineer*, Feb. 12, 1892, Diagram. |
| 8·10 | 7·22 | ... | 1·33 ,, | 0·89 | Witz, *Moteurs*, p. 215. |
| 110 | 75·86 | ... | 1·34 ,, | 0·69 | ,, ,, p. 220, Diagram. |

TRIALS, 1878-1891.

| Indicated H.P. | Brake H.P. | Consumption of Oil per I.H.P. per hour. | Consumption of Oil per B.H.P. per hour. | Mechanical efficiency. | Heating Value. T.U. per lb. | Authority. |
|---|---|---|---|---|---|---|
| 5·39 net | 4·26 | 2·16 lbs. | 2·72 lbs. | 0·79 | 11,000 | Clerk, *Gas Engines*, p. 159. |
| 9·36 | 7·72 | 0·69 lb. | 0·84 lb. | 0·82 | 19,700 | *Institution Civil Engineers*, vol. cix., 1891. |
| 7·40 | 6·76 | 0·86 ,, | 0·94 ,, | 0·91 | ... | ,, ,, |
| 5·24 | 4·49 | 1·06 ,, | 1·24 ,, | 0·85 | 19,000 | ,, ,, |
| 25 nom. | 25·5 | ... | 0·88 pint | ... | ... | ,, ,, |
| 6·74 | ... | ... | 0·9 ,, | ... | ... | *Engineering*, Oct. 9, 1891. |
| 6·2 | 4·28 | 0·66 lb. | 0·96 lb. | 0·68 | ... | *The Engineer*, Dec. 4, 1891. |
| 4 nom. | 5·3 | ... | 0·885 ,, | ... | ... | *Institution Civil Engineers*, vol. cix., 1891. |
| 4 nom. | 4·15 | ... | 0·92 ,, | ... | ... | Witz, *Moteurs*, p. 215. |
| ... | 2·88 | ... | 0·93 ,, | ... | ... | ,, ,, p. 216. |
| 16 nom. | 16·67 | ... | 1 ,, | ... | ... | ,, ,, p. 219. |
| ... | 6·7 | ... | 0·83 ,, | ... | ... | *Zeits. Ver. Deutscher Ing.*, Aug. 29, 1891. |

## TABLE OF AIR

| Air Engine. | Experiment made by | Place and Date. | Dimensions of Engine. | | Duration of Test. | No. of Revolutions. |
|---|---|---|---|---|---|---|
| | | | Diam. of Cyl. | Stroke. | | |
| Buckett, . . . . | Ingrey | Caloric Co. | 24 in. | 16 in. | ... | 61 |
| Bailey, . . . . . | ... | ... | 14⅝ ,, | 6⅞ ,, | ... | 106 |
| Bénier, . . . . . | Slaby | Cologne, 1887 | 13·4 ,, | 13·8 ,, | 2½ hrs. | 117·6 |

## GAS ENGINE

| Air Engine. | Experiment made by | Place and Date. | Dimensions of Engine. | | Duration of Test. | No. of Revolutions. |
|---|---|---|---|---|---|---|
| | | | Diam. of Cyl. | Stroke. | | |
| *American Otto (twin cylinder). | H. Sprangler. | Schleicher, Schlum & Co., Philadelphia, May, 1893. | 14⅝ in. | 25 in. | 3 days. | 160 |

* Particulars received too late for incorporation in body of work.

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| Indicated H.P. | Brake H.P. | Consumption of Fuel per I.H.P. per hour. | Consumption of Fuel per B.H.P. per hour. | Mechanical efficiency. | Authority. |
|---|---|---|---|---|---|
| 20·2 | 14·39 | 1·8 lbs. | 2·54 lbs. | 0·71 | Jenkin, *Gas and Caloric Engines*, *Inst. C. E.*, 1883. |
| 2·37 | 1·31 | 4·2 „ | 7·6 „ | 0·55 | „ „ „ „ |
| 5·85 | 4·03 | 3·1 „ | 3·6 „ | 0·69 | *Zeits. Ver. Deutscher Ing.*, vol. xxxiii., p. 89. |

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*Note.*—See also List of *Proceedings*, Periodicals, and Reports, in *Trials of Gas, Oil, and Air Engines.* Pages 400-407.

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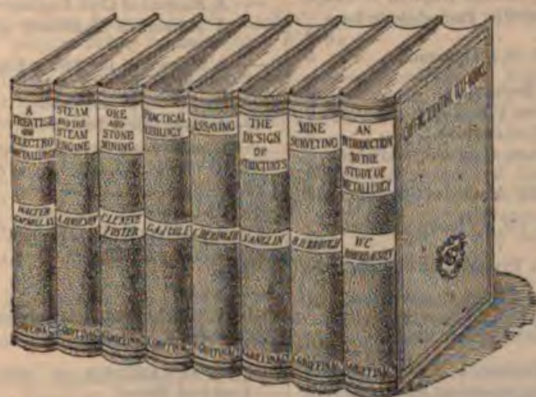


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